

THE
PLATINUM DEPOSITS AND
MINES OF SOUTH AFRICA

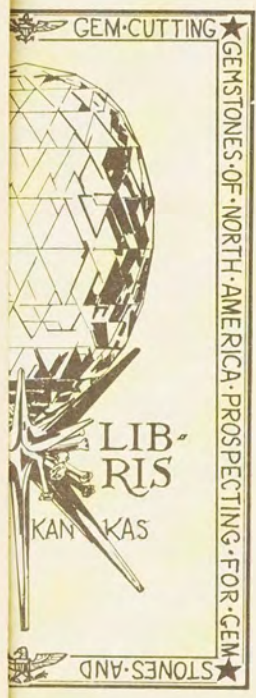
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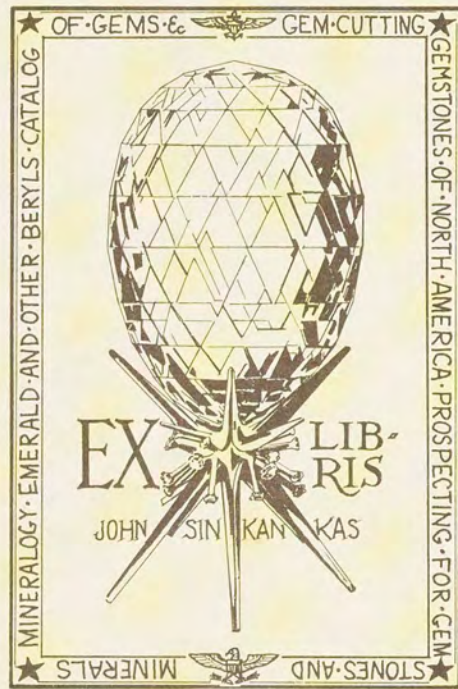
CONSULTING GEOLOGIST AND MINING ENGINEER, LATE SENIOR
GEOLOGIST, GEOLOGICAL SURVEY, UNION OF SOUTH AFRICA

WITH 38 FULL-PAGE PLATES, CHARTS,
AND 37 TEXT ILLUSTRATIONS

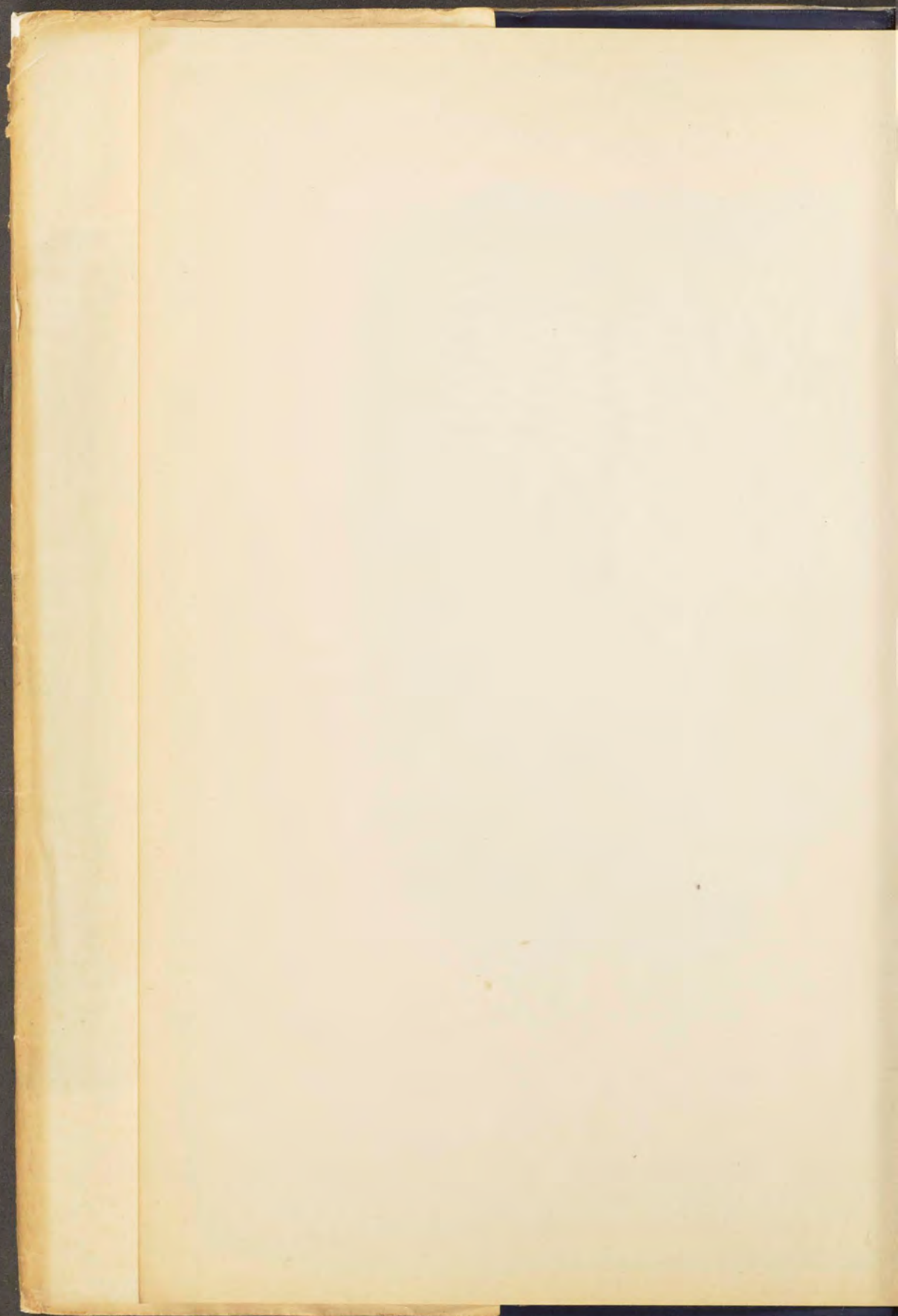




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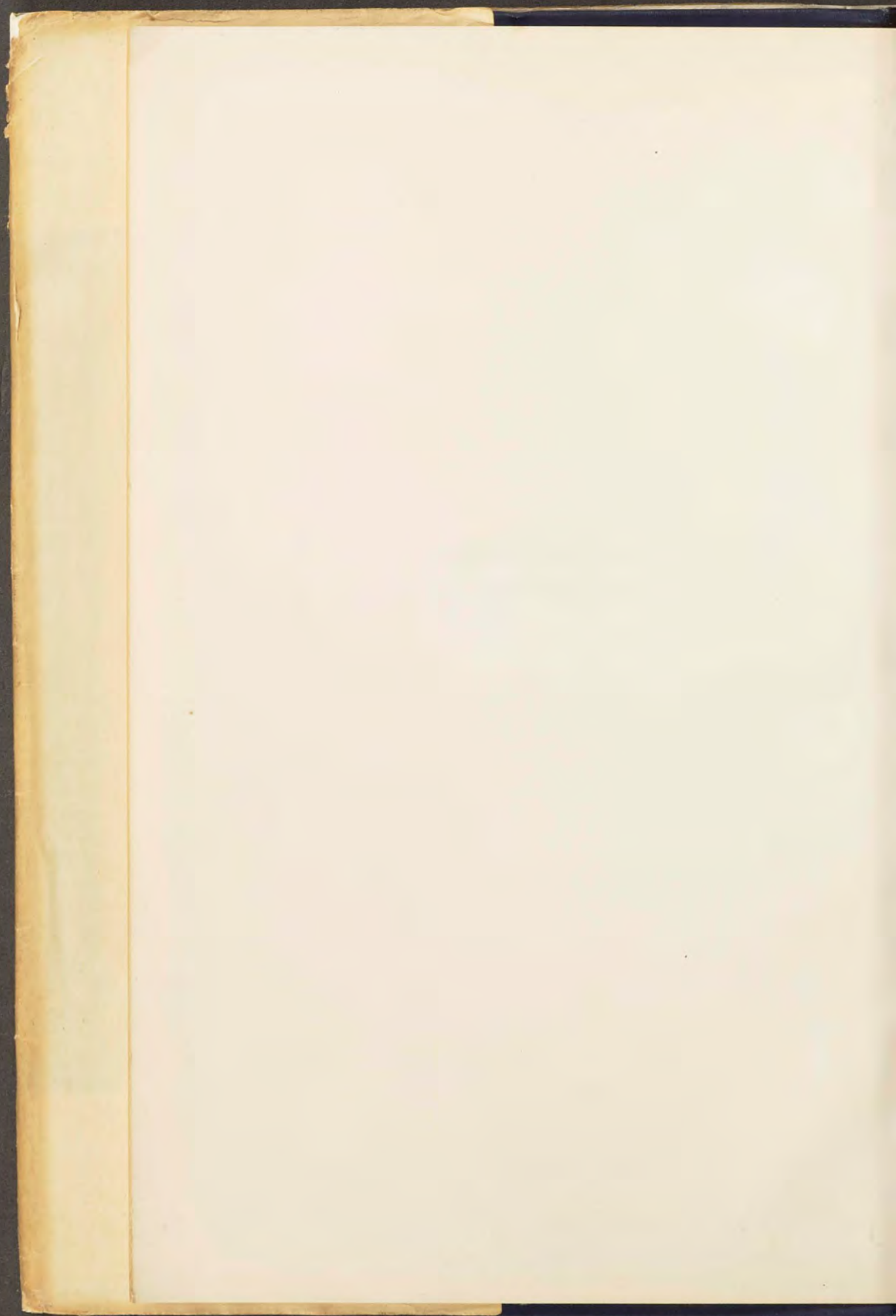
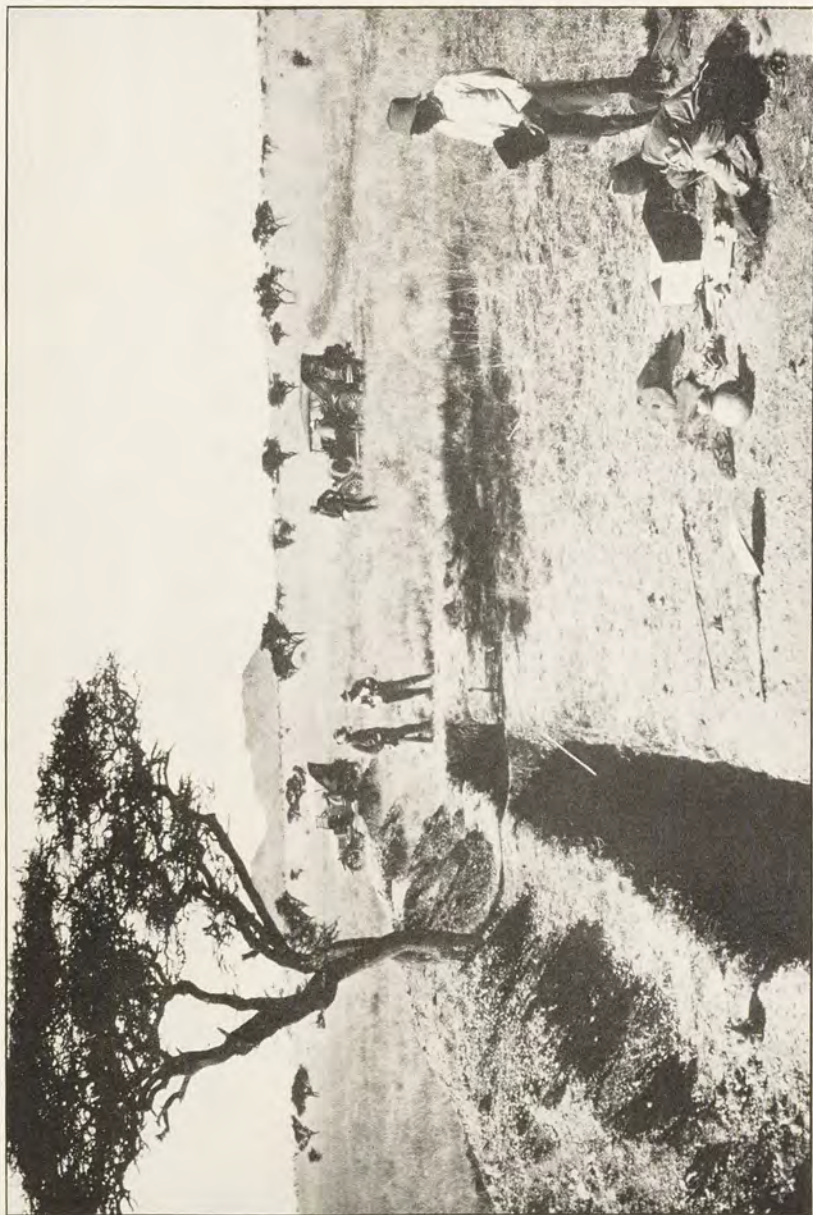




PLATE I



Prospecting trench on Merensky Platinum Horizon, Swarikip, No. 989, Rustenburg district.

USL
RTL008307

The Platinum Deposits and Mines of South Africa

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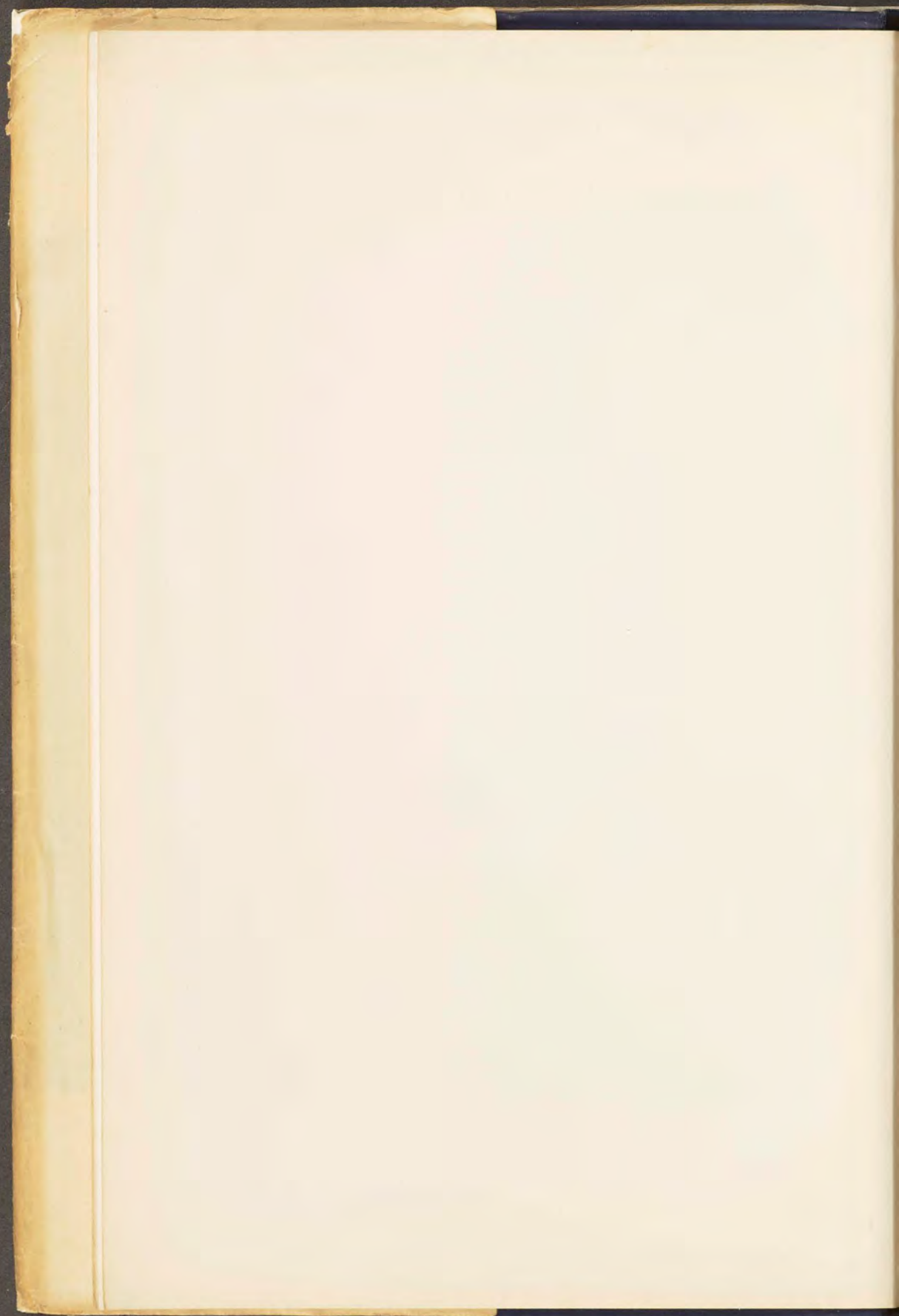
WITH A CHAPTER ON
THE MINERAGRAPHY AND SPECTROGRAPHY OF
THE SULPHIDIC PLATINUM ORES OF THE
BUSHVELD COMPLEX

BY
PROFESSOR DR H. SCHNEIDERHÖHN
FREIBURG I. BR.

WITH THIRTY-EIGHT PLATES AND
THIRTY-SEVEN FIGURES IN TEXT

OLIVER AND BOYD
EDINBURGH: TWEEDDALE COURT
LONDON: 33 PATERNOSTER ROW, E.C.4

1929



TO
DR HANS MERENSKY
MINING GEOLOGIST, SUPER-PROSPECTOR AND
BEST OF FRIENDS
I DEDICATE THIS BOOK



PREFACE

THE Transvaal, that marvellous storehouse of mineral wealth, has become of recent years an important producer of the platinum metals. She is destined to become the world's leading producer as her primary deposits of these metals are incomparably the greatest.

The sequence of events that led to their discovery has been given elsewhere. It need here only be recalled that the finding in 1923, by Adolph Erasmus, of the remarkable lode deposits of the Waterberg district gave a great impetus to the search for platinum in South Africa. It was followed in September 1924, by the discovery of the Bushveld deposits which transcend in magnitude and importance anything that had hitherto been dreamt of in the way of primary platinum occurrences.

The story of the opening up of these deposits has often been told, but the writer feels that sufficient credit has never been given to Dr Hans Merensky for the part that he played in this epic of mineral exploration. It was he who discovered both the dunite deposits and the Merensky Horizon in the Lydenburg district. It was he who located the most important deposits in the Potgietersrust area. It was he, finally, who, when all hope had been abandoned of finding the Merensky Horizon in the Rustenburg district, not only located it, but, with the assistance of Messrs D. McKerrell, D. Mare, J. Ellis and M. Weber, traced it over scores of miles.

The main object of the present book is to describe these remarkable Transvaal deposits and call attention to their enormous economic possibilities. It was intended originally to deal with them only. As, however, there are also very interesting occurrences outside the Transvaal, and South Africa, geologically speaking, constitutes an entity, it was decided to extend its scope by including the deposits of the Cape Province and Southern Rhodesia, as had already been done previously in a paper, "The Occurrence of the Platinum

Metals in South Africa," which the writer contributed in 1925 to *Economic Geology*.

The strictly geological part of the book follows the same lines as that paper, though certain aspects of the subject have been considerably elaborated.

In preparing the mineralogical section the writer was fortunate enough to secure the collaboration of Professor Dr Hans Schneiderhöhn, whose masterly chapter (No. XVII) on the mineragraphy and spectrography of the sulphide ores of the Bushveld Complex is a contribution of outstanding importance to the sciences of mineralogy and economic geology.

The remainder of the book must, except so far as certain chapters are concerned, be regarded merely as a summary of our present state of knowledge of a subject so vast and complex, and yet withal so alluring and provocative of discussion, that it may safely be prophesied that the last word on it will never be spoken.

The book has been prepared hurriedly, mainly in spare hours snatched from a busy professional career. In its preparation the writer has received the cordial assistance and co-operation of numerous friends and colleagues, of whom mention must be made of the following:—G. A. E. Becker, H. Merensky, G. H. Beatty, W. E. Turvey, E. T. Mellor, R. A. Cooper, H. R. Adam, J. H. Healey, J. Carleton Jones, H. B. Maufe, E. Golding, G. J. V. Clarence, R. H. Hewston, K. Richardson, E. L. Gay Roberts, L. J. Krige, L. T. Nel, F. C. Vaughan, J. E. Muller, T. H. Harris, E. Judells, A. A. English, R. Courtney, H. E. Inder, E. Herbert Frankel, F. G. Krause, Frank G. Green, G. H. Stanley, J. L. van Eyssen, C. J. Meyer, F. Wartenweiler, W. W. Jenkins, J. G. Carr, P. Trotzig, S. Loxton, L. Wipplinger, P. Kovaloff, A. W. Rogers, Malcolm Maclaren, A. L. Hall, Sir Robert Kotze, and Professors L. Duparc and E. Kaiser.

Special thanks are also due to Professor Arthur Holmes, of Durham University, who has kindly undertaken the arduous task of revising the proofs and seeing the book through the press.

JOHANNESBURG,
11th February 1929.

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THE PLATINUM DEPOSITS AND MINES OF SOUTH AFRICA

CHAPTER I

THE PLATINUM GROUP METALS

THOUGH known in South America as early as the sixteenth century,¹ the first actual reference to platinum that can be found is in a narrative, published in 1748 by Don Antonio de Ulloa y Gracia de la Torre, of a journey to Peru. In this work he mentions the occurrence of the metal, together with gold, in New Granada, now Colombia. It is referred to as *Platino del Pinto*, *plata* being the Spanish diminutive for silver and *Pinto* the name of the river in the gravels of which it was first found.

Grains of the metal had, however, reached Sir William Watson, an English physicist, as early as 1741, and it was he who first described it in 1750 as a new "semi-metal or metalloid."

Its remarkable properties early began to attract notice, and the interest aroused in it amongst scientists led, in the early part of the nineteenth century, to a series of epoch-making investigations on crude platinum by the most eminent scientists of the day, among whom special mention must be made of Wollaston.

These investigations soon established that the grains of the crude metal experimented with were not composed entirely of platinum, but of a complex mixture of several metals which, while somewhat resembling platinum, had very distinct and

¹ No really ancient workings for platinum have been found. The writer has, however, pointed out elsewhere—*Trans. Geol. Soc. of S. Africa*, 1925, p. 111—that the pre-European miners responsible for the big, old copper workings on the farm Tweefontein, No. 1033, situated 15 miles north-north-east of Potgietersrust, may, in the process of smelting these ores for copper, also have extracted a good deal of platinum and probably palladium. It is quite possible, therefore, that copper ornaments and implements made from these ores may be found to contain both metals.

valuable properties of their own.¹ Five other metals, namely, palladium, iridium, rhodium, ruthenium and osmium were actually identified. These with platinum constitute what are known as the *Platinum Group Metals*.

By this time native platinum had also been found in the gold washings of the Verkhnigisetsk in the Urals, and production from this and other districts in the Urals actually began in 1824. Since then the Urals, except for one brief period, have remained the principal source of production, with Colombia second.

Up to the outbreak of the Great War, Russia, through her Uralian deposits, had actually been responsible for over 90 per cent. of the world's total output of the metal, and was still at that time producing 92 per cent. of the annual output. Thus, for the six years ending 31st December 1914, the average annual outputs of the principal platinum producing countries were as follows:—

	Ounces (troy).
Russia	200,000
Colombia	12,080
Australia and Tasmania	790
United States of America	594
Borneo and Sumatra	180
Burma	46
Canada	33

Owing to the complete disorganisation of the Russian platinum industry due to the war and the revolution following it, the Uralian output dropped from 210,000 ounces in 1912 to 5500 ounces in 1921. Since then it has recovered rapidly, but is still less than one half of what it was before the Great War. Colombia, on the other hand, has greatly increased her output since 1914, as has Canada, and within the past four years South Africa, a new and important producer, has entered the field.

The following table² gives the world's production of "new" platinum³ from 1914 to the end of 1927, the South African figures for 1928 being included. South Africa, it should be stated, now ranks third in importance as a source of platinum after Russia and Colombia, though exploitation of our most

¹ Cf. *The Platinum Metals*, by Ernest A. Smith, London, 1925, p. 9.

² Except for the data for 1928, this table as it stands is quoted from Dr George F. Kunz's interesting article "The Production of Platinum" in *The Mineral Industry*, vol. xxxvi, pp. 461-476.

³ As opposed to "secondary" or scrap platinum.

important deposits has not yet begun. She has, moreover, for some years been the leading producer of osmiridium, with Tasmania second; Russia, Colombia, Papua, and Japan following in the order stated.

World's Production of Platinum(*a*) in ounces troy, fine platinum.

Year.	Australia.	Canada (<i>b</i>).	Colombia.	Russia.	South Africa.	United States(<i>b</i>).	Total.
1914	185	...	16,264 (<i>d</i>)	202,000 (<i>c</i>)	...	1,484	219,933
1915	43	475	18,749 (<i>d</i>)	104,000 (<i>c</i>)	...	1,190 (<i>e</i>)	124,457
1916	62	1,040	25,592 (<i>d</i>)	53,000 (<i>c</i>)	...	2,780 (<i>e</i>)	82,474
1917	197	1,036	26,421 (<i>d</i>)	98,474	...	6,280 (<i>e</i>)	132,408
1918	461	705	34,266 (<i>d</i>)	43,181	...	9,740 (<i>e</i>)	78,613
1919	162	690	32,236 (<i>d</i>)	39,425	...	10,460 (<i>e</i>)	72,513
1920	640	4,345	33,500 (<i>c</i>)	11,323	...	11,500 (<i>e</i>)	61,308
1921	189	5,412	34,000 (<i>c</i>)	5,500	...	2,899	48,000
1922	61	4,802	43,574 (<i>d</i>)	22,500	...	1,988	72,935
1923	445	6,810	40,676 (<i>d</i>)	34,700	...	2,114	84,745
1924	490	9,186	46,533 (<i>d</i>)	56,900	...	3,523	116,632
1925	436	8,698	56,000 (<i>e</i>)	94,800	...	4,325	164,259
1926	...	9,521	55,000 (<i>e</i>)	92,700	4,951	4,923	167,500 (<i>e</i>)
1927	...	11,217	...	...	10,431	4,449	...
1928	...	...	...	...	17,828 ¹	...	...

¹ It will be shown that these figures relate only to platinum metals actually sold.

(*a*) Estimated content of fine platinum contained in crude platinum output. There has been a small production in some years from India, Borneo, Japan and other countries, but none of importance. (*b*) Platinum of domestic source recovered by refiners. (*c*) Estimated by J. M. Hill, U.S. Bur. of Mines. (*d*) Exports. (*e*) Estimated.

Sources of Supply.—The deposits of the platinum metals cover a wide range of geological associations. The most important occurrences, however, are in ultra-basic and basic igneous rocks and in detrital deposits derived from them.

Until quite recently the platinum of commerce was derived exclusively from alluvial deposits in which the crude metal occurs in very fine flattened and rounded grains. These rarely exceed a pea in size, though nuggets much larger than this are occasionally found.

For the past twenty years small but growing amounts of the metal have been recovered as a by-product of the smelting and refining of the nickel ores at Sudbury in Canada. More recently small amounts have also been recovered from the primary dunite occurrences of the Urals, and since 1925, when the great primary deposits of the Bushveld Igneous Complex were first opened up, there has been a steadily increasing

production from this source which will, in the near future, show a very considerable expansion.

Scrap Platinum.—Apart from "new" platinum with which we have so far been dealing, considerable amounts of platinum in the form of old and worn articles and chemical residues are now collected and returned to the refineries, where they are re-treated and sold again. The "scrap" or "secondary" platinum industry is particularly active in the United States where, during 1927, 46,127 ounces were recovered.

There is also a very considerable output of "secondary" iridium, palladium, and other platinum metals in the United States. The output of "secondary" iridium for 1927 totalled 1810 ounces.

Classification, Properties and Uses of the Platinum Group Metals.

The several platinum group metals have already been mentioned by name. They fall naturally into two groups, namely:—

- (1) The light platinum metals: palladium, ruthenium, and rhodium, with specific gravities ranging from 12.10 to 12.14, and
- (2) The heavy platinum metals: platinum, iridium, and osmium, with specific gravities ranging from 21.50 to 22.47.

Some useful data about these metals are given in the following table¹:—

Data about the Platinum Group Metals.

	Light.			Heavy.		
	Pd.	Rh.	Ru.	Pt.	Ir.	Os.
Atomic weight	106.7	102.9	101.7	195.2	193.1	190.9
Specific gravity	12.16	12.44	12.10	21.50	22.42	22.47
Atomic volume	8.9	8.5	8.3	9.1	8.6	8.5
Melting point.	1549.2°	1950°	2450°(?)	1755°	2350°(?)	2500°(?)
Boiling point.	2200°	>2500°	>2700°	4300°	>4800°	>5300°
Hardness	4.8	...	6.5	4.3	6.5	7.0
Crystal system	Isometric	Isometric	Hexagonal	Isometric	Isometric	Hexagonal
Valency	1, 2, 3	2, 3, 4	2, 3, 4, 8	2, 4	2, 3, 4	2, 3, 4, 8

¹ The table is based on data given by J. W. Mellor, *Modern Inorganic Chemistry*, p. 641; and F. C. Carter, *The Platinum Metals and their Alloys*. "Technical Publication" No. 70, *Am. Inst. Min. Eng.*, 1928.

The several metals of the platinum group are all capable of existing as colloids. It will be shown subsequently that in at least one South African occurrence both platinum and palladium were probably deposited in this state.

The Individual Metals.

Platinum.—Platinum is by far the most important and widely used member of the group.

It is a fairly hard greyish-white metal which, in addition to being exceedingly malleable and ductile, is practically infusible and unoxidisable and unattacked by all acids except *aqua regia*. It is a good conductor of electricity and heat, but has the lowest coefficient of expansion of any metal. It is capable of absorbing large quantities of hydrogen and other gases, the gases thus occluded then becoming more "active." For this reason it is used as a catalyst.

It alloys readily with quite a number of metals, forming, as a rule, complete solid solutions. Some of the more important of such alloys are platinum-gold, platinum-iridium, platinum-palladium, platinum-osmium, platinum-rhodium, platinum-ruthenium, platinum-silver, and platinum-nickel.

The principal uses of the metal at the present time are in jewellery, where it is employed chiefly (*a*) in platinum and platinum-gold chains; (*b*) for setting diamonds; and (*c*) in engagement rings. A platinum setting shows up the true colour of diamonds, whereas gold gives them an undesirable yellow tint. Apart from this, platinum holds diamonds more securely than gold. The platinum used for jewellery, as will be pointed out, is usually hardened with iridium.

Other important uses are in the chemical industry where it is largely employed as a catalyst and for laboratory ware, for which it is unrivalled,¹ for physical apparatus, in the electrical industry, in magnetos, thermo couples, electrodes and furnace linings, for electro-plating, photography, wireless, dentistry, in the explosives industry for fuses, for surgical appliances, and in the manufacture of artificial silk, where the liquid rayon is squirted through minute holes in the bottom of a cup or spinnerette made of hardened platinum.

Platinum was also used in Russia for coinage purposes between 1828 and 1841, but, owing to the impossibility at

¹ Cf. Carter, F. C., *loc. cit.*

that time of stabilising the price of the metal, its use was discontinued.

Palladium.—Palladium ranks next to platinum in importance. Its colour is between that of platinum and silver. It is malleable and ductile, takes a high polish and resists tarnish.

Its principal uses are in jewellery and dentistry and as a catalyst. In the jewellery trade it is fairly extensively used as a substitute for platinum. According to George F. Kunz,¹ pure palladium, like pure platinum, is too soft for use alone but, alloyed with 5 per cent. of platinum and 3 per cent. of ruthenium, it wears very well.

It is also used for making the circles of astronomical instruments and theodolites and in the construction of the springs and movements of clocks.

Palladium forms a number of useful alloys, including palladium-copper, palladium-gold, and palladium-silver.

A satisfactory palladium-plating solution has now been developed and, since the plate is white and non-tarnishing, it should find very extensive application.²

From the point of view of the South African platinum industry it is of great importance that further uses should be found for the metal, as it will be produced in considerable quantities from the ores of the Merensky Horizon.

Iridium.—Iridium is of a brilliant white colour and very brittle. It is, as already indicated, characterised by its hardness and infusibility.

It is extensively used for hardening platinum which for many purposes, *e.g.* chemical work, jewellery and electrical work, is too soft to be used by itself. Thus, the "medium hard" platinum of the jewellery trade contains 5 per cent. of iridium and "hard" platinum 10 per cent. of the metal.

These platinum-iridium alloys are the most important of all the platinum alloys.

Iridium-osmium alloys are also of considerable importance. The natural alloy (osmiridium) is very hard and is used extensively for gold fountain-pen points. For this purpose the Tasmanian, Papuan and Japanese material is of suitable grain. The South African material is too fine and goes to the metal refiners.

¹ *Loc. cit.*

² *Cf. Carter, F. C., loc. cit.*

Synthetic iridium-osmium alloys also find extensive application on account of their hardness and extremely high fusion points.

Osmium.—Osmium is a bluish-grey metal which oxidises readily, giving off poisonous fumes of osmium tetroxide. It was at one time used in the electric lamp industry, but at present it is employed mainly for making synthetic osmium alloys for pen points and sparking points. It is also used for hardening platinum, and as a staining and preserving fluid in microscopy and for recording finger prints.

Rhodium.—Rhodium is a bluish-white metal resembling aluminium in colour. It is malleable and ductile at red heat. It is used principally in the preparation of platinum and rhodium alloys. These have a lower rate of volatilisation and do not crystallise so readily. They are therefore used to some extent in crucible ware. One preferred alloy used for this purpose is that containing $3\frac{1}{2}$ per cent. of rhodium.¹ The same valuable properties lead to the use of these alloys in precious metal thermo-couples.

Ruthenium.—Ruthenium is of greyish-white colour and resembles platinum. It is used for hardening platinum and palladium and seems to act similarly to osmium. It has, however, an advantage over that metal in being less easily oxidised. Certain ruthenium salts are also used in the dyeing industry.

Consumption of the Platinum Metals.—The relative importance of the several industries consuming platinum metals in the United States, the principal market for these metals, is given in the table on p. 8, also quoted from Dr Kunz's article in *The Mineral Industry*.

It should be stated that roughly one-third of the platinum consumed in the United States comes from working "secondary" or scrap platinum, one-third is a by-product of the refining of nickel, copper, and other metals, and one-third is imported.

The Platinum Stamping Law.—The New York Platinum Stamping Law, which is the result of many years of conferences and discussions among the various branches of the jewellery trade, was given effect on 1st January 1928.

It provides, *inter alia*, that "an article containing at least 985/1000ths of metals of the platinum group, when solder is

¹ Cf. Carter, F. C., *loc. cit.*

not used, and at least 950/1000ths parts, when solder is used, may be marked "platinum," provided that the metals of the platinum group other than platinum shall amount to not more than 50/1000ths parts of the article."¹

Consumption of Platinum Metals in the United States by Industries
(in ounces troy).

Industry.	Platinum.	Iridium.	Palladium.	Others.	Total.	Percentage of Total.
1926.						
Chemical . .	10,253	145	213	288	10,839	6.32
Electrical . .	16,765	1,608	3,508	185	22,066	12.87
Dental . .	8,542	131	11,063	...	19,736	11.51
Jewellery . .	85,908	2,949	7,770	454	97,081	56.54
Miscellaneous .	17,381	581	2,181	1,751	21,894	12.76
	138,849	5,414	24,735	2,618	171,616	100.00
1927.						
Chemical . .	11,010	101	180	175	11,466	7.66
Electrical . .	14,905	1,618	2,491	121	19,135	12.77
Dental . .	7,504	153	12,194	...	19,851	13.25
Jewellery . .	86,036	4,059	3,706	329	94,130	62.81
Miscellaneous .	3,176	305	312	1,311	5,104	3.41
	122,631	6,236	18,883	1,936	149,686	99.90

It is to be hoped that the law will be extended to other states and countries, as it will assist materially in stabilising the prices of the metals.

Prices of the Platinum Metals.

Platinum.—Ever since production on a big scale of this metal began, its market price has fluctuated within very wide limits.

Prior to 1896 the price of the refined metal was between 30s. and 50s. per ounce troy. It then rose rapidly, reaching 90s. in 1905 and 160s. in 1906, the maximum price up to that time. This rapid rise in price led to great activity in the Uralian fields, the output of which in consequence rose considerably. As a result of this increased production the price of the metal receded in 1908 to 85s. per ounce. In 1909 it recovered somewhat, the average price being 89s. During the year following there was again a rapid rise, the average price in 1910 being 182s. Between this date and the outbreak of the

¹ Cf. Kunz, Geo. F., *The Mineral Industry*, 1927, p. 541.

Great War it was stabilised round about 180s. by French financial interests. At the time of the outbreak of the war it was actually 185s.

The average price in London since 1914 is given in the following table¹:—

Average Price in shillings per ounce troy of refined platinum in London.

Year.	Price.	Year.	Price.
1914.	185	1922.	410
1915.	200	1923.	499
1916.	200	1924.	538
1917.	290	1925.	498
1918.	400	1926.	467
1919.	433	1927.	320
1920.	561	1928.	335
1921.	392		

The highest price recorded during this period was in January 1920, when for a short time the refined metal was sold for 770s. per ounce. The lowest price reached was in July 1927, when it was sold for 270s. per ounce. The cause of the sudden drop in price in 1927 will be discussed later.

The latest (December 1928) official quotation for refined platinum is £15, 15s. per ounce, but for fair sized parcels there are sellers at down to £14, 10s. per ounce.

Crude platinum sells at from 5 to 15 per cent. below refined, its price depending, however, upon the proportion of iridium present.

Palladium.—The course of palladium has been much the same as that of platinum. During the war period it rose to 500s. and actually reached 800s. per ounce early in 1920. Thereafter it dropped, but recovered in 1923, when it stood again at 350s. Since then it has averaged between £14 and £9 per ounce. The latest official price is still £10, 10s. per ounce, but merchant parcels are being offered down to £9, 10s. per ounce.

Iridium.—The price of iridium, the most precious of the platinum metals, is, like that of platinum, subject to rapid fluctuations. Sold round about 260s. per ounce until 1914, the price rose rapidly during the war and the years following it until, in 1925, it was nearly £100. In 1926 it had dropped

¹ Compiled from figures given by *The Mining Magazine*, London.

again to £32. At present (January 1929) the price of iridium, sponge and powder, is between £57 and £60 per ounce, after having touched £90 in February 1928.

Osmium.—Osmium sells round about 240s. per ounce.

Rhodium.—The present average price of this metal is about 225s. per ounce troy.

Ruthenium.—The average price of ruthenium in recent years has been about 195s.

It should be pointed out that the prices given for osmium, rhodium, and ruthenium are purely nominal. Their sale is a matter for negotiation and is regulated by the quantity and quality required.

CHAPTER II

THE MINERALOGY OF THE PLATINUM METALS

UNTIL the Bushveld deposits were opened up the platinum metals had been found almost exclusively in the native or elementary state, mostly as natural metallic alloys. The only exceptions were *sperrylite*, platinum-diarsenide (PtAs_2) and *laurite*, a sulphide of ruthenium and osmium (probably RuS_2), found in the platinum-bearing gravels of Borneo.

Pure native platinum is a rare curiosity. As a rule the metal is alloyed with iron and subordinate amounts of the other members of the platinum group, these and the iron being in solid solution in the platinum. Gold, copper, nickel, and cobalt are also sometimes present, and most varieties of crude platinum enclose minute crystals of osmiridium. According to the percentage of iron in solid solution two main varieties of native platinum are distinguished,¹ namely:—

- (1) *Ferroplatinum*, which is dark grey to almost black in colour and contains from 71 to 78 per cent. of platinum and from 16 to 21 per cent. of iron; and
- (2) *Polyxene*, which is light steel-grey to silver-white in colour and contains from 80 to 90 per cent. of platinum and from 6 to 11 per cent. of iron.

According as iridium is present in solid solution in these two varieties of platinum or not, two sub-varieties of each are distinguished, namely, α and β ferroplatinum and α and β polyxene. α ferroplatinum and α polyxene contain from 1 to 5.5 per cent. of iridium, while β ferroplatinum and β polyxene are free from that element.

Another interesting variety, only recently recognised by Professor Zavaritzky (64),² may be named *cuproplatinum* since

¹ Vysotzki, N., *The Ural and Siberian Platinum Fields. The Geology and World Distribution of Platinum*, Petrograd, 1928, Part II., pp. 112 *et seq.*

² Numbers in parentheses refer to the Bibliography at the end of the volume.

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it contains from 8 to 13 per cent. of copper. It occurs as thin shells rimming crystals and grains of ferroplatinum in the primary unweathered dunite ores of the Nijnie Tagilsky region of the Urals. It is characterised, apart from its high copper content, by being very readily etched by *aqua regia*.

Apart from natural alloys of the platinum metals composed predominantly of platinum, there are others which are either free from platinum or into the composition of which that metal barely enters. This will be apparent from the following list (pp. 13-14) of the native platinum metals and their alloys which is based on one prepared by Professor P. Kovaloff.¹ Minerals, the existence of which cannot be considered definitely proved, are marked with an asterisk, and here it should be stated that a great deal of work remains to be done on the mineragraphy of the species listed. Some of them are probably mixtures of two or more minerals.

Platinum Group Metals found in South Africa.—A brief account may next be given of the minerals of the platinum group metals found in the South African occurrences.

The great deposits of the Bushveld Complex, in addition to furnishing crystals of sperrylite of a size previously undreamt of, have already yielded two minerals totally new to science. One of them, a platinum sulph-arsenide, widely distributed in the ore of the Merensky Horizon, was first recognised by R. A. Cooper (43). For this mineral, after he had convinced himself by chemical and other tests that it was an entirely new species, the writer proposed the name *cooperite* in honour of its discoverer. The other, a palladium antimonide, described by H. R. Adam (56),² from the pegmatitic ore of Tweefontein, No. 1033, Potgietersrust district,³ it is proposed, with the approval of Mr H. R. Adam and Professor H. Schneiderhöhn, to name *stibiopalladinite*.

Cooperite.³—Cooperite occurs in minute subhedral and anhedral grains in the sulphide ore of the Merensky Horizon, some of the grains being so small as to be barely perceptible even under the microscope. It is of greyish-white or yellowish-white colour with bright metallic lustre. No complete crystals

¹ *S. African Min. and Eng. Journ.*, May 1926.

² See Chapter XII.

³ The mineragraphy and spectrography of cooperite and stibiopalladinite are fully dealt with by Professor Schneiderhöhn in Chapter XVII.

I Native Platinum Group.

Subdivision 1—Platinum Minerals:—

	Pt.	Fe.	Cu.	Ir.	Pd.
1. Platinum (Pt)	100	0	...	0	0
2. Ferroplatinum α (Pt, Fe, Ir)	71-78	16-21	...	1-4.5	0.2-0.8
3. Ferroplatinum β (Pt, Fe)	73-78	16-20	...	0	...
4. Polyxene α (Pt, Fe, Ir)	80-90	6-11	...	1-5.5	0-2.5
5. Polyxene β (Pt, Fe)	80-90	6-10	...	0	...
6. Cuproplatinum (Pt, Fe, Cu)	70	12-15	8-13	1-2	0.16-0.25

Subdivision 2—Iridium Minerals:—

	Pt.	Fe.	Ir.	Pd.
7. Platiniridium (Pt, Ir, Fe)	56	28	4	0
8. Iridium (Ir, Pt)	20	0	77	0

Subdivision 3—Palladium Minerals:—

	Pt.	Pd.	Ir.	Fe.
9. Palladic platinum (Pt, Pd)	73-74	21.8	0.1-0.9	0
10. Palladic platinum (Pt, Pd, Ir)	83-84	3.0-3.7	1.3-3.6	0
11. Palladic platinum* (Pt, Pd, Ir, Fe)	...	...	...	...
12. Palladium (isometric)* (Pd)	0	100	0	0
13. Allo-palladium (rhombohedral) (Pd)	0	100	0	0
14. Potarite ¹ (Pd, Hg)	...	...	...	...

Subdivision 4—Rhodium Minerals:—

	Rh.	Pt.	Ir.	Fe.
15. Rhodic platinum (Pt, Rh, Ir? Fe?)	4.6	...	...	...
16. Rhodium* (Rh)	100	...	...	...

¹ Palladium-amalgam, cf. Spencer, L. J., *Miner. Mag.*, 1927, vol. xxi., p. 117.

II. Osmiridium Group.

	Ir.	Os.	Rh.	Pt.
17. Syserskite (osmiridium) (Os, Ir)	17.0	69.9	4.5	0.2
	Ru.	Pd.	Fe.	Cu.
	8.9	...	0.03	0.03
18. Nevyanskite (iridosmium) (Ir, Os)	46.8-77.2	21.0-49.3	0.5-7.7	0.1-3.1
	Ru.	Pd.	Fe.	Cu.
	0.0-5	0-tr	0.1-4	0.0-9
19. Rhuthenic nevyanskite (Ir, Os, Ru)	35.5-57.8	33.5-54.4	0.5-7	0.0-6
	Ru.	Pd.	Fe.	Cu.
	4.7-8.5	...	tr-1.5	0.0-8

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II. Osmiridium Group—(continued).

20. Rhodic nevyanskite (Ir, Os, Rh)	Ir.	Os.	Rh.	Pt.
	70.0-70.4	17.2 17.3	11.3-17.2	...
	Ru.	Pd.	Fe.	Cu.
	...	...	tr-O	O-tr
21. Platinic nevyanskite (Ir, Os, Pt)	Ir.	Os.	Rh.	Pt.
	55.2	27.3	1.5	10.1
	Ru.	Pd.	Fe.	Cu.
	5.9	tr	tr	tr
22. Osmite (Ir, Os)	Ir.	Os.	Rh.	
	10	80	5	...

III. Gold-Platinum Metals Group.

23. Palladic gold (porpexite) (Au, Pd)	Au.	Ag.	Pd.	Pt.	Ir.
	86.0-91.1	tr-4.2	8.2-11.6	0.0-1	...
		Rh.	Fe.	Cu.	Bi.
	...	...	O-tr	O-tr	...
24. Rhodic gold (rhodite) (Au, Rh)	Au.	Ag.	Pd.	Pt.	Ir.
	57.0-88.4	...	...	tr	...
		Rh.	Fe.	Cu.	Bi.
	...	11.6-43	...	...	...
25. Iridic gold (Au, Ir)	Au.	Ag.	Pd.	Pt.	Ir.
	62.1	2.1	tr	3.8	30.4
		Rh.	Fe.	Cu.	Bi.
	...	0.6	0.03	tr	...
26. Platinic gold (Au, Pt)	Au.	Ag.	Pd.	Pt.	Ir.
	84.6	2.9	...	...	...
		Rh.	Fe.	Cu.	Bi.
	...	0.2	0.9	...	...

IV. Iron-Platinum Group.

27. Platinic iron * (Fe, Pt, Ni ?)	Fe.	Pt.		
	91.85 ?	8.15	...	...
28. Ferrite (Fe, Ni, Co, Pt)	Fe.	Pt.	Ni.	Co.
	98.5-100	0.0-1	0.0-6	0.0-3
	Cu.	Mn.	P.	As.
	0.0-4	0.0-8	0.1-0	0.0-3

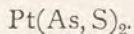
of the mineral have as yet been found. In the concentrate obtained from panning the ore it generally appears as irregular, elongated, rectangular plates and as prismatic individuals with fluted ends and edges due to polysynthetic twinning (p. 227). It is anisotropic and such crystal forms as can be recognised suggest that it is orthorhombic. It is much softer than sperrylite, the hardness being between 4 and 5.

The mineral has remarkable chemical properties. It is quite insoluble in acids, even prolonged treatment with aqua regia having no effect on it. On being heated to even a moderate temperature on a glass tube or platinum foil, it gives off sulphur and arsenic, leaving a purely metallic residue which is found to have a peculiar reddish-bronze tarnish. This residue is fairly readily soluble in aqua regia, and consists predominantly of platinum accompanied by subordinate amounts of palladium.

An analysis of the mineral by R. A. Cooper gave the following result:—

	Per cent.
Pt	64.2
Pd	9.4
S	17.7
As	7.7

The formula calculated from the above analysis is:—



Cooperite or a mineral closely resembling it is, as we shall learn, also present in the unweathered hortonolite-dunite ores of the Lydenburg district.¹

Stibiopalladinite.—This mineral has so far been definitely identified only in the ores of contact metasomatic and pegmatitic deposits of the Potgietersrust district.² It occurs in irregular rounded grains up to 2 mm. across, which sometimes show crystal faces. It is white in colour, but has a peculiar yellowish-pink or bronzy-pink tint. It is isotropic and appears thus to crystallise in the isometric system. It too is much softer than sperrylite. As might be expected from its composition it differs fundamentally in its chemical properties from cooperite. It gives up antimony when heated in a glass tube and is fairly readily soluble even in dilute hot aqua regia.

¹ Cf. Chapter VII.

² Cf. Chapter XIII.

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A chemical analysis by H. R. Adam showed :—

	Per cent.
Pd	70.4
Sb	26.0
Insoluble	1.4
Fe (As Fe_2O_3)	0.9
	98.7

A partial analysis by D. Millin showed :—

	Per cent.
Pd	70.35
Sb	27.95

The formula calculated from these analyses is :—



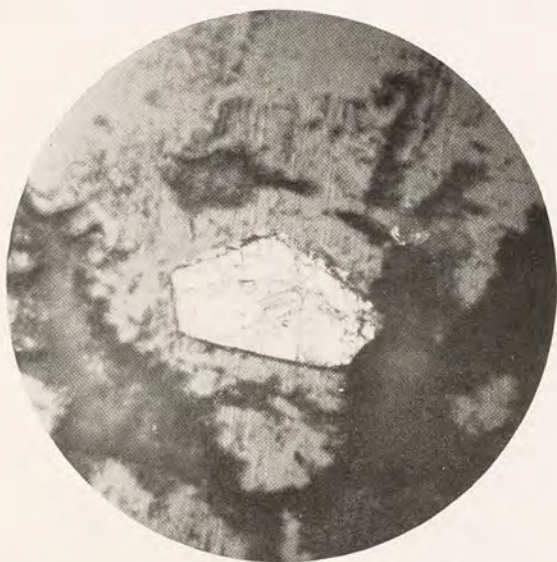
It is of interest to record that in the contact metasomatic and pegmatitic deposits north-north-west of Potgietersrust stibiopalladinite and sperrylite occur side by side, the complete segregation of platinum and palladium being very remarkable.

Sperrylite is also widely distributed in the sulphidic platinum ores of the Bushveld Complex, occurring, as a rule, in minute well-formed crystals characterised by a brilliant tin-white colour and well-marked conchoidal fracture. The most remarkable occurrence, however, is in the pegmatitic deposits on Tweefontein, No. 1033, in the Potgietersrust district, which have yielded well-formed crystals up to 1.85 cm. across. The biggest crystal so far found actually measured 1.85 by 1.625 by 1.5 cm. along the cubic axes, and weighed 33.75 gm. It is seen on the right in Plate II.1.

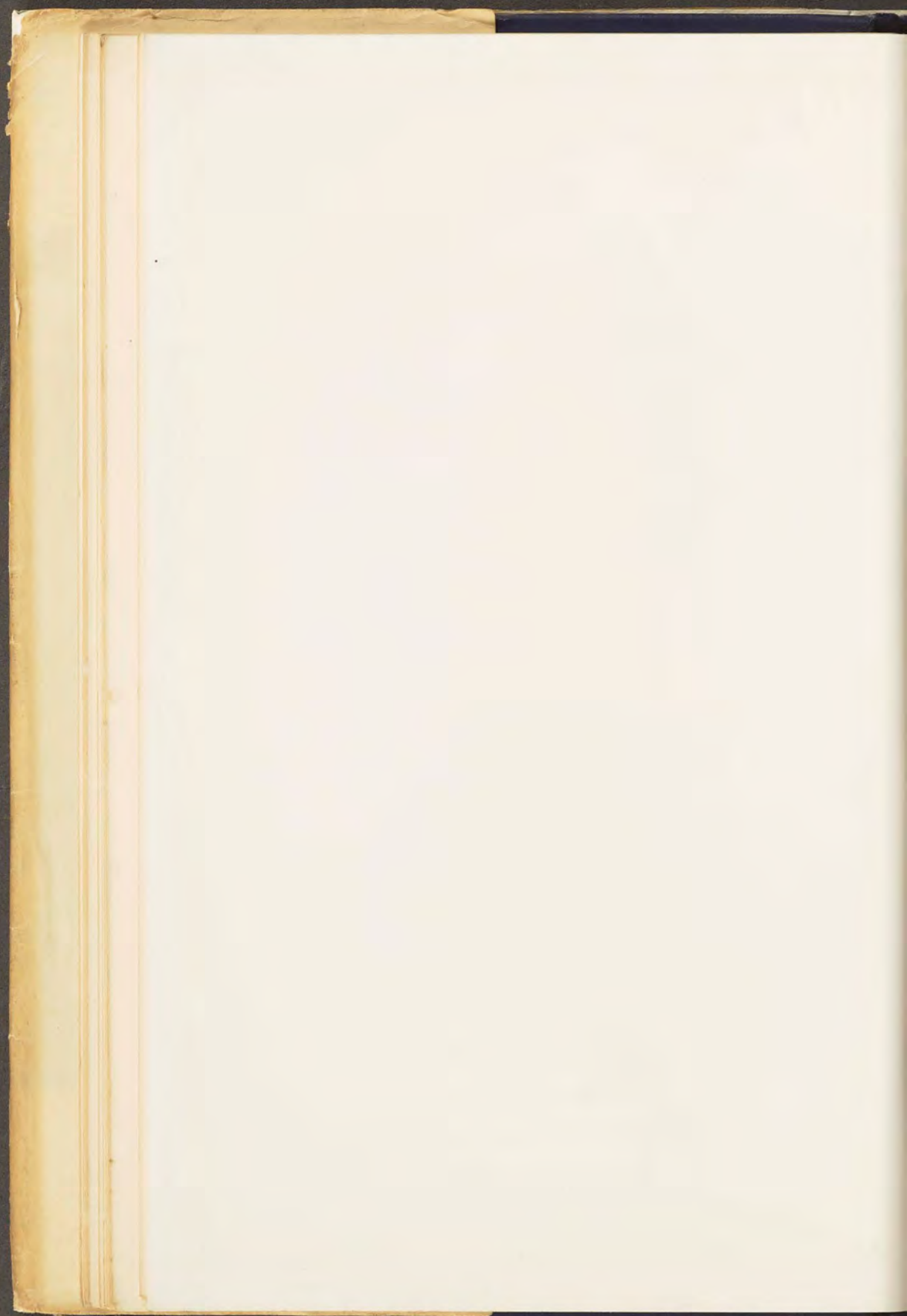
The crystals are of bright tin-white colour with splendid lustre. Many of them look as though they had been polished and are objects of great beauty. They have been described by Dr L. J. Spencer (60) and the present writer (34). They are mostly of cubic habit, but the cube and the octahedron are sometimes equally developed. Other forms are invariably present, the edges of the cube and octahedron being generally bevelled by narrow crystal faces that reflect the light as from numerous brilliant facets. The following forms have been identified: the rhombic dodecahedron, the trapezohedron and the pyritohedron or tetrahexahedron {210}. The edges of the crystals and these minute faces are generally curved as in the diamond. Dr Spencer noted beautiful terraces of growth on some of the cubical crystals submitted to him.



1. Big crystals of sperrylite from Tweefontein, No. 1033, north-north-west of Potgietersrust. The crystal on the left is now in the British Museum; that in the matrix at the back is in the Geological Survey Museum, Pretoria.



2. Section of pentagonal dodecahedron of sperrylite imbedded in pyroxene. Ore of Merensky Horizon, Helena, No. 220, Lydenburg district. Polished section.
 × 200.



In these big crystals the hemihedral symmetry of the mineral is not as a rule evident, but the writer has in his possession the cast and portion of a crystal 1.1 cm. across which is definitely pyritohedral in habit. The minute microscopic crystals found imbedded in the sulphidic ore of the Merensky Horizon, and in that of the contact deposits north-north-west of Potgietersrust are also in part sharp-edged pentagonal dodecahedra (Plate II.2).

A chemical analysis by R. A. Cooper of a crystal from Tweefontein gave the following result:—

	Per cent.	
Pt	54.83	
Rh	1.66	
Pd	Nil	
S	Nil	
As	39.89	
Fe (FeO)	0.92	} Gangue
CaO		
MgO		
SiO ₂		
Al ₂ O ₃		
Total	99.28	
Specific Gravity	10.6	

According to this analysis the Bushveld sperrylite is considerably poorer in arsenic than the sperrylite of other localities.

The mineralogical and chemical properties of these three very interesting minerals found in the sulphidic ores of the Bushveld Complex are given in the following table (p. 18), in which has been incorporated a good deal of data borrowed from a similar table that Professor Schneiderhöhn had prepared for Chapter XVII.

Sperrylite is highly resistant to atmospheric weathering even in the presence of acid solutions, as is evidenced by the occurrence on Tweefontein, No. 1033, Potgietersrust district, of brilliant unaltered crystals of the mineral imbedded in gossan derived from complete oxidation and leaching of copper-nickel-iron sulphides.

Stibiopalladinite also appears to be fairly stable, but nothing is known of its behaviour at the actual outcrop.

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Cooperite appears to be converted at and near the surface into metallic platinum.

Table showing Properties of Sperrylite, Cooperite, and Stibiopalladinite.

Mineral.	Sperrylite.	Cooperite.	Stibiopalladinite.
Crystal System . . .	Isometric (Pyritohedral)	Orthorhombic?	Isometric?
Twinning . . .	Untwinned	Polysynthetically twinned	Untwinned.
Cleavage . . .	None	None	None.
Fracture . . .	Conchoidal	Conchoidal	Uneven.
Colour . . .	Tin-white	White with distinct greyish - yellow tint	White with yellowish- or bronzy-pink tint.
Lustre . . .	Brilliant	Bright metallic	Metallic.
Hardness . . .	6-7	4-5	4-5.
Specific gravity . . .	10.6	...	9.5.
Chemical composition .	PtAs ₂	Pt(As, S) ₂	Pd ₂ Sb.
Behaviour toward acids.	Very slightly soluble in hot aqua regia	Insoluble in hot aqua regia	Soluble in hot aqua regia.
Behaviour in closed tube	Decrepitates slightly but remains unaltered otherwise	Decomposed giving off S and As	Decomposed giving off Sb.
Behaviour in open tube.	White sublimate of As ₂ O ₅ formed	Gives off SO ₂ , white sublimate of As ₂ O ₅ formed	Gives off SO ₂ and white sublimate of Sb ₂ O ₃ formed.
Capacity for taking polish	Good	Good	Good.
Reflectivity—			
in air . . .	High	High	High.
with oil immersion.	"	"	"
Behaviour in polarised light	Isotropic	Distinctly anisotropic	Isotropic or very faintly anisotropic.
Etching properties—			
HCl (conc.) . . .	Negative	Negative	Negative.
HNO ₃ " . . .	"	"	"
Aqua regia . . .	"	"	Etched so as to bring out grain contacts.
HCl (conc.) with solid KClO ₃	"	"	Deeply etched bringing out internal structure.

It will be shown presently that only part of the platinum present in the sulphidic ores of the Merensky Horizon is in the form of cooperite and sperrylite. The remainder, according to the brilliant researches of Professor Schneiderhöhn (Chapter XVII.), and the bulk of the palladium in these ores are in solid solution in the earlier formed magmatic sulphides.

Professor Schneiderhöhn has also established that on the weathering of these sulphides the platinum and palladium dissolved in them are segregated in colloform grains exhibiting a concentric zonal structure.

Platinum Minerals in Dunite Deposits of the Lydenburg District.—In the dunite deposits of the Lydenburg district¹ the bulk of the platinum is present in the metallic state in well-formed crystals, nuggets, and irregular grains. On freshly-cut surfaces its colour is silvery-white, but on exposure to weathering it assumes a brownish rusty tarnish. Some of the crystals and grains are magnetic, others non-magnetic, but all of the platinum tested, on being hammered, not only becomes magnetic but develops polarity.

	I.	II.	III.	IV.
Pt . . .	84.75	84.00	98.30	97.50
Os . . .	} 0.95	2.30	1.00	{ 0.40 ¹
Ir . . .				
Rh . . .	n.d.	0.20	0.30	0.67
Pd . . .	0.53	0.30	0.40	1.23
Ni . . .	0.48	...	...	...
Cu . . .	1.28	trace	...	...
Fe . . .	11.98	12.80	...	...
Total . .	99.97	99.60	100.00	100.00

¹ Osmiridium.

- I. Picked clean grains of silvery-white platinum from hand-crushed dunite, 200-foot level, Onverwacht Mine. Anal., R. A. Cooper.
- II. Picked crystals of crude platinum from outcrop, Onverwacht Mine. Anal., F. W. Watson and R. A. Cooper.
- III. Relative proportions of the platinum metals in a sample of crude platinum, Onverwacht Mine. Anal., R. A. Cooper and F. W. Watson.
- IV. Relative proportions of the platinum metals in a representative sample of "metallics," *i.e.* grains and crystals of crude platinum recovered by concentration at the Maandagshoek Mill from crushed dunite of the Mooihoek and Driekop "pipes." Iron and copper were not determined.

The crystals, which range up to 1 mm. across, are for the most part of cubic habit, the cube being generally combined with the octahedron and the dodecahedron (Plate III.1). One crystal from Onverwacht was found to be made up of a combination of cube, octahedron, and tetrahedron. Some of the irregular nuggety forms have small cubes projecting from their corners. Others are pitted with depressions of circular or cubic outline. Some of the elongated grains show irregular terminations at one end and crystal faces at the other, indicating that the crystallisation of the platinum overlapped that of some of the other minerals present in the rock. Rounded,

¹ See Chapter VII.

oval-shaped nuggets up to $\frac{3}{8}$ inch in diameter are occasionally met with in the Onverwacht occurrence.

Polished sections of the platinum, on being etched, show that it encloses minute crystals of osmiridium (Plate III.2). Larger crystals of this rare mineral are also sometimes seen, the osmiridium being occasionally visible to the naked eye in plates up to 0.5 mm. across. Some of the Onverwacht platinum contains up to 5 per cent. of osmiridium.

The platinum itself contains up to 12 per cent. of iron in solid solution; also some copper and nickel and subordinate amounts of iridium, rhodium, and palladium.

The table on p. 19 gives analyses of representative samples.

As chemical tests prove that the platinum contains small amounts of iridium in solid solution, and it is always light in colour, it may be classed as a *polyxene* in the classification of Professor Vysotzki, though the iron content is higher than the limit there assigned to a *polyxene*.

Below water-level in all three of the Lydenburg dunite mines, metallic platinum is accompanied by considerable amounts of what was at first taken to be a platinum sulph-arsenide, which, according to an analysis by J. Craighead,¹ has the following composition.

	Per cent.			
Pt	.	.	.	59.3
As	.	.	.	36.9
S	.	.	.	3.7

An examination of a concentrate composed of the alleged mineral shows, however, that this consists of minute cubes and cubo-octahedrons of sperrylite accompanied by plates of a mineral having the properties of cooperite. The sperrylite cubes, according to tests made by R. A. Cooper, are very strongly attacked by aqua regia, while the cooperite (?) is unattacked by it. In the Onverwacht Mine about 25 per cent. of the platinum recovered from the lower levels is in the form of these two minerals which are especially abundant in the finer portion of the gravity concentrate. They are also present below water-level in the Mooihoek and Driekop Mines, but in smaller quantities.

The Onverwacht dunite also contains other natural platinum alloys. Thus, R. A. Cooper² found that after treating

¹ Quoted by R. A. Cooper (43).

² Personal communication to the writer.

PLATE III



1. Cubical crystal of platinum from hortonolite-dunite, Onverwacht Mine, Lydenburg district. $\times 32$. Edges of the cube are truncated by the faces of the rhombic dodecahedron, and its corners by the faces of the octahedron.



2. Crystals of osmiridium imbedded in platinum (black is open field). Polished section prepared from crystal of platinum from Onverwacht Mine, Lydenburg district. $\times 300$.



the flotation concentrate with weak aqua regia, to dissolve out the normal polyxene, there could be dissolved out of the residue remaining, with stronger acid, certain grains of distinctive appearance. These yielded a solution containing 70 per cent. of platinum and 30 per cent. of palladium, indicating an alloy of this composition. After the above treatment there remained an almost insoluble residue containing osmiridium and roughly 3 per cent. of rhodium and 3 per cent. of ruthenium. Other minerals of the platinum metals are thus clearly present. It is probable, indeed, that, as in the case of the Uralian dunites, a whole series of solid solutions of Pt, Pd, Rh, Ru, Ir, and Os are contained in the ore. Cuproplatinum is also probably present below water-level, as the platinum from below water-level is richer in copper than that from the oxidised zone. A fine field for research here awaits the mineralogist.

Platinum Minerals in the Ores of the Potgietersrust Field.—The gravity concentrate obtained from treating a mixture of oxidised and unoxidised magmatic and contact metasomatic ores at the mill of the Potgietersrust Platinums, Limited, near Potgietersrust, contains sperrylite, stibiopalladinite, rectangular plates of a mineral taken to be cooperite, metallic platinum alloyed with palladium, and gold. In the flotation concentrate, on the other hand, which consists mainly of sulphides, the bulk of the platinum and palladium are in solid solution in the sulphides, as proved by the investigations of Professor Schneiderhöhn which have been confirmed chemically by H. R. Adam. According to H. R. Adam, about one-half of the platinum and one-tenth of the palladium in these mixed ores are "free."

It should be added that the platinum metals and minerals of the Potgietersrust ores are, on the whole, much coarser than those in the Merensky Horizon as developed on the Rustenburg fields.

Platinum Minerals in the Lode Deposits of the Waterberg District.—In the remarkable lode deposits of the Waterberg district, described in Chapter XIX., the platinum, as is generally the case with lode platinum, is alloyed with palladium and gold, containing from 7 to 45 per cent. of the former and from 0.3 to 3 per cent. of the latter. It occurs in peculiar colloform grains which, on being etched, are found to be conspicuously zonal in structure and to be made up of alternating layers of palladium-

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rich and palladium-poor platinum. Part of the palladium can be extracted by boiling with one to one hot hydrochloric acid. Analyses of the crude platinum of these deposits are given in Chapter XIX (p. 260).

Platinum Minerals in the "Osmiridium" Concentrate of the Witwatersrand.—The so-called "osmiridium" concentrate of the Witwatersrand¹ contains a number of distinct minerals. It consists predominantly of osmiridium apparently accompanied by quite subordinate amounts of iridosmium. There are also present small rounded and oval-shaped greyish-white grains which are taken to be platinum, and small rough-looking pitted granules of a dark-coloured metal which may be metallic ruthenium or an alloy very rich in it. If this latter inference should prove to be correct, South Africa will have yielded yet another new platinum-group mineral. Further mineralogical work on these very interesting concentrates is urgently needed.

The composition of representative samples of osmiridium concentrate from the Witwatersrand mines is given in Chapter V (p. 34).

¹ See Chapter V.

PLATE IV



1. Small nuggets of platinum from the eluvium on Onverwacht, No. 330,
Lydenburg district. $\times 6$.



2. Irregular grains of platinum (white) imbedded in hortonolite-dunite (black)
of Onverwacht Mine. Photomicrograph of polished section. $\times 23$.



CHAPTER III

THE OCCURRENCE OF THE PLATINUM GROUP METALS IN SOUTHERN AFRICA

IT has been established during the past five years that South Africa has large reserves of the platinum metals, the principal occurrences, as already indicated, being in the Transvaal. Previous to this period there had been two disastrous platinum booms based on alleged discoveries of the metal that were never substantiated; and desultory attempts had been made to work the Insizwa deposits in which metals of the platinum group occur in association with magmatic nickel-copper sulphides. It was only in 1921, however, that metals of this group began to figure for the first time in the already long list of the mineral products of the Union of South Africa. In that year the recovery of "osmiridium,"¹ initiated on a small scale at the Modderfontein Deep Levels Mine as early as June 1919, was begun in earnest at several of the larger mines in the Far East Rand. The total production in 1921 was 509 ounces valued at £6801. In 1928 it had grown to 5670.6 ounces and there were actually sold 5913.45 ounces valued at £85,682. In 1925 there were sold 6055 ounces valued at £170,995. Since then the output has remained fairly constant, but, owing to the great drop in the price of osmiridium, the value of the output is only about one half of what it was in 1925.

Almost simultaneously with the beginning of the recovery on a big scale of osmiridium came the opening up of the remarkable but ill-starred platinum deposits in the Waterberg district of the Transvaal, followed in the latter part of 1924 by the very important discoveries in the Lydenburg district of the same province.

During 1925 even more important discoveries were made in the Potgietersrust and Rustenburg districts in the norite

¹ The "osmiridium," as previously stated, is a concentrate containing several minerals.

zone of the Bushveld Complex which, as the writer has pointed out elsewhere, probably contains in the aggregate more platinum than all the rest of the earth's crust accessible to man. These discoveries were followed by others in the Northern Transvaal and Southern Rhodesia.

It is known now that the platinum metals are found in Southern Africa in the most diverse circumstances, and in rocks ranging in age from the most ancient to the most recent.

The geographical distribution of the principal deposits is shown on the accompanying map (Fig. 1). In order to render clear their distribution in the scale of geological time, the several occurrences are enumerated in the following table in relation to the principal geological formations, the various groups of rocks being arranged in their correct stratigraphical sequence so far as this is known.

From this table and from what follows in Chapters IV. to XII., it will be evident that platinum-bearing rocks are unusually abundant in South Africa. In no other part of the world, so far as the writer is aware, are they so widely distributed, and no other countries certainly can show such concentrations of platinum in mother rock. It will be noted too that platinum-bearing rocks have been represented in practically all the periods of igneous activity in the long geological history of the subcontinent, even going back to the earliest Archæan.

The widespread occurrence of the platinum metals is thus clearly due to some deeply underlying cause that has operated continuously throughout geological time. In endeavouring to seek this cause it will be necessary first of all to consider briefly the probable constitution and structure of the outer part of the earth. There is a fair consensus of opinion among geologists that this is made up of concentric shells of rock of progressively increasing density. There is also very strong evidence to support the view of Daly¹ that the continental or *sial* crust and the ocean basin are underlain by a universal shell of basaltic composition which, as the writer has shown elsewhere, is probably composed of amphibolite, gabbroitic and granulitic rocks.² It is probable³ that this shell merges

¹ *Igneous Rocks and their Origin*, pp. 164-166.

² *South African Journal of Science*, 1928, pp. 127-148.

³ *Cf. Wagner, loc. cit.*

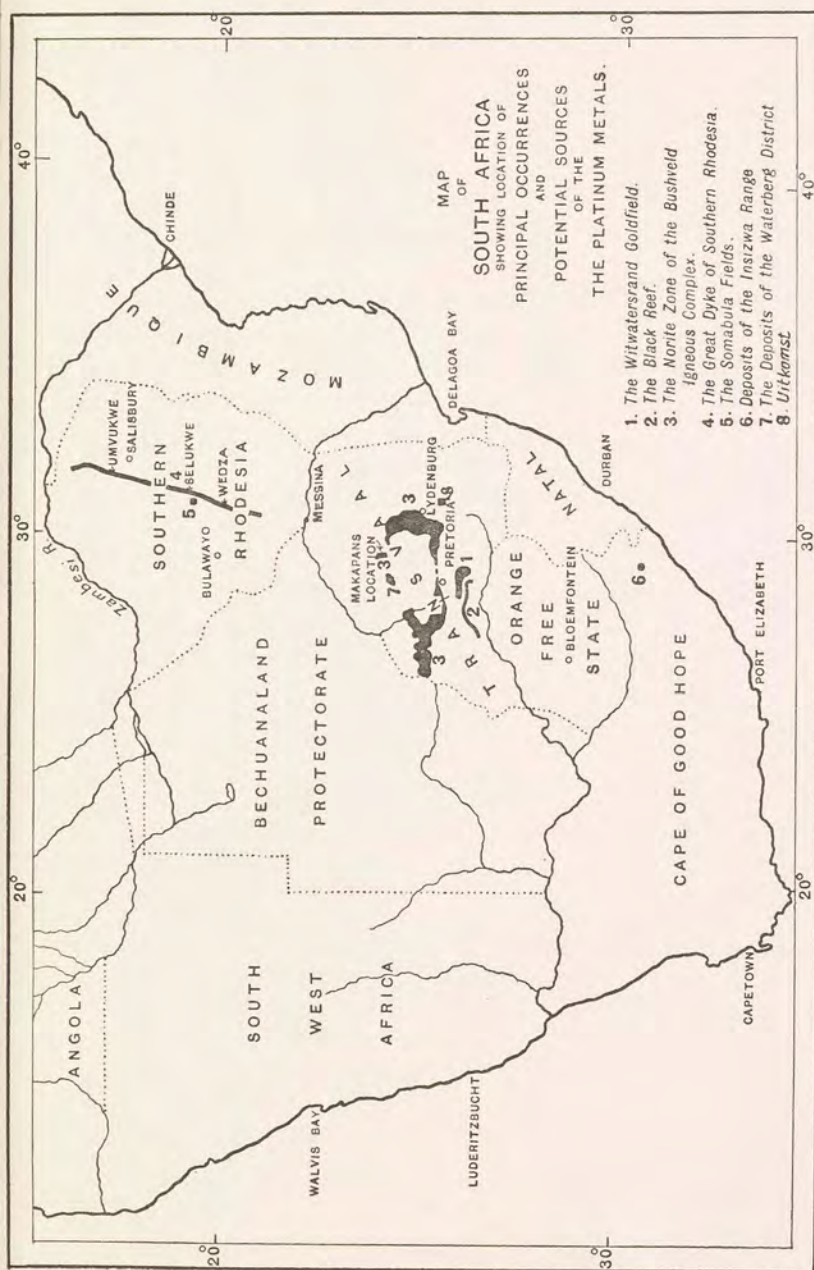


FIG. 1.

Geological Formations and Occurrences of the Platinum Metals.

Stratified Formations.	Igneous and Volcanic Activity.	Occurrences of Platinum Metals.
Cainozoic	Sands, river gravels, Marine inshore beds, lateritic deposits.	Alluvial deposits of Waterberg Dist. Eluvial and alluvial deposits of the Lydenburg, Potgietersrust and Rustenburg Districts. Lode deposits of Waterberg District. Occurrence in kimberlite.
Cretaceous	Sands, clays, Conglomerates, Marine limestones.	
Karoo System (Carboniferous-Triassic)	Sandstones, Shales, Mudstones, Tillite	Occurrences in Karroo Dolerite and rocks allied to Karroo Dolerite. Occurrence in diamond-bearing conglomerates and gravels of Somabula Fields.
Cape System (Devonian)	Sandstones, Shales, Conglomerate, Tillite.	
Waterberg System . .	Sandstone, Quartzite, Conglomerate.	Intrusive nepheline and allied syenites. Extrusive basaltic lavas.
Transvaal System (Pre-Cambrian?)	Quartzites, shales, Dolomite, Conglomerate.	
Ventersdorp-Witwatersrand System (Pre-Cambrian)	Quartzite, Conglomerate, Shales, taconite.	Occurrences in ultrabasic and basic rocks of Bushveld Igneous Complex and of the Great Dyke of Southern Rhodesia. Occurrences of hydrosamine in the Black Reef.
Swaziland System (Pre-Cambrian)	Schists, phyllites, limestones, marbles, conglomerates, taconite.	
		Occurrence of "osmiridium" in the gold-bearing conglomerates of the Witwatersrand System.
		Occurrence in altered pyroxenite on Uitkomst No 183, Eastern Transvaal.
		Occurrences in Southern Rhodesia in serpentine and chromite.
		Occurrences (?) in other ultrabasic rocks of the Swaziland System.
		Occurrence in quartz vein in Old Granite.

downward into a universal layer of eclogite, and this in turn into a very thick peridotite shell—the *sima* zone of Suess.¹

The *sima* zone is probably, as Suess originally suggested, the principal home of the platinum metals. Parts of the overlying zone of basaltic composition must, however, also have been comparatively rich in them since, judging by the average composition of the rocks of which the Bushveld Igneous Complex is made up, the magma that gave rise to it emanated from this zone.

Granting the correctness of this conclusion, then, the unusual abundance of platinum metals in the igneous rocks of South Africa could easily be explained on the assumption that the portion of the *sima* zone underlying the subcontinent is abnormally rich in platinum. Even if this should be so it would still be necessary, however, to account for the linear arrangement of the principal deposits described in the preceding pages. Reference to Fig. 1 will show that despite their being so widely separated in age these are all confined to a more or less meridional belt lying between longitude E. 26° and longitude E. $30^{\circ} 40'$; while the occurrences of the Insizwa and Lydenburg areas and those of the Great Dyke of Southern Rhodesia actually lie between longitude E. $29^{\circ} 20'$ and longitude E. $30^{\circ} 40'$.² Far to the north of this we find that the Kilo Gold Field in the north-eastern part of the Belgian Congo (lat. N. 2°), in which gold is associated with palladium and platinum, also lies between longitude E. $29^{\circ} 50'$ and longitude E. $30^{\circ} 15'$.

It is clear, therefore, that we have to do here with a great *platinum belt* that cuts indiscriminately across the oldest and youngest geological formations, completely disregarding geological structures and structure lines in the more superficial parts of the earth's crust.

To J. E. Spurr we owe the conception of great *ore canals* of this nature, stable throughout geological time, along which the most important mineral deposits of the world are situated, and which pursue their way across continents regardless of rock formations and of the folding and faulting in them; their position being thus evidently determined by structural features

¹ *The Face of the Earth*, vol. iv., p. 544.

² The position of longitude E. 30° as shown in Fig. 1 is not quite correct.

in the portion of the earth's crust underlying that exposed to our view by denudation.¹ Spurr's idea is that when one of these ore canals taps a portion of a sub-crustal layer particularly rich, let us say, in copper, the igneous rocks along the line of the ore canal will be abnormally rich in copper, and so with silver and other metals.

Again accepting the correctness of this hypothesis we may conceive the presence below the eastern part of Southern Africa² of a great platinum canal that, from the earliest geological times, facilitated the upward transference of the metals of the platinum group from an especially platinum-rich portion of the *sima* zone into the rocks forming the continental crust.³

It would appear, therefore, that the portion of the zone of basaltic composition underlying the southern part of Africa is abnormally rich in the platinum metals, and that there exists beneath the eastern part of the South African Shield a great ore canal that throughout the geological ages has facilitated the upward transference of these metals. Further platinum discoveries are to be expected along the course of the canal.

It is proposed to describe in the sequel the various sources and potential sources of supply of the platinum metals listed in the table on page 4.

¹ *The Ore Magmas*, chapter xi.

² It may with a slight deviation to the north-east extend right across Africa, inasmuch as the platinum deposits in Abyssinia (long. E. $35^{\circ} 5'$) are also only a few degrees off the presumed line of the "canal." Platinum occurs here in an olivine-dunite found in the valley of the Birbir River, a tributary of the Baro (Duparc, L., and Molly, E., "Les Gisements Platinifères du Birbir, Abyssinie," Ext. *Bull. Suisse de Min. Petr.*, tome viii, 1, 1928.

³ Incidentally it may be remarked that, as the platinum belt includes the greater part of the remarkable South-east African gold province, responsible at the present time for over 55 per cent. of the world's annual production of that metal, and as gold is not infrequently associated with platinum in the primary occurrences, the gold probably came up along the same canal as the platinum and along one paralleling it on the east.

CHAPTER IV

OCCURRENCES IN ULTRABASIC AND BASIC ROCKS OF THE SWAZILAND SYSTEM

THESE rocks include several types of serpentine and silicified serpentine,¹ talc-schist, harzburgite, websterite, cortlandite, hornblende-websterite, hornblendite, and enstatite-hornblendite.² They are probably, as suggested by R. B. Young (10), the source of the "osmiridium" in the conglomerates of the Witwatersrand System; the fact that the "osmiridium" is invariably accompanied by crystals and grains of chromite lending support to this view.

So far no discoveries have been made of osmiridium in the matrix, but during 1928 there was opened up on the farm Uitkomst, No. 183, situated in the Carolina district, Eastern Transvaal, an interesting occurrence of platinum in one of these ancient ultrabasic rocks.

Occurrence on Uitkomst, No. 183.—On this farm there was struck, in the course of opening up chrysotile asbestos deposits, a big sill of highly altered pyroxenite carrying platinum in association with magmatic nickel-copper-iron sulphides. The occurrence in some respects bears a close analogy to those of Sudbury in Canada. The precise nature of the intrusion is not at present known. It is apparently, however, as suggested above, a big sill dipping at 10 degrees to the north-east.

The platinum-bearing rock in its present condition consists mainly of bladed crystals of pale bluish-green secondary hornblende. Originally it was clearly made up predominantly of colourless diopside accompanied by enstatite and magmatic sulphides, and subordinate amounts of plagioclase, apatite,

¹ Kynaston, H., *Trans. Geol. Soc. S. Africa*, 1907, p. 51; also Hall, A. L., "The Geology of the Barberton Mining District," *Memoir No. 9, Geol. Surv. Union of S. Africa*, pp. 195-209; and Maufe, H. B., "An Outline of the Geology of Southern Rhodesia," *Short Report No. 17, Geol. Surv. of S. Rhodesia*, p. 5.

² Hall, A. L., "Corundum in the Northern and Eastern Transvaal," *Memoir No. 15, Geol. Surv. Union of S. Africa*, pp. 46-50.

and magnetite. A fair amount of secondary chlorite is also present. The hornblende is orientated crystallographically with the pyroxenes from which it has clearly developed.

The rock is interspersed with irregular specks and patches of magmatic sulphides. These are interstitial to and moulded on the silicates, and are found on examination to consist of the usual intimate intergrowths of pyrrhotite, pentlandite and chalcopyrite. Chalcopyrite in places also forms big irregular patches in the ore.

The analysis of one sample examined showed 2.8 per cent. of nickel, 1.72 per cent. of copper, and 6.4 dwts. of platinum per ton. The platinum appears to be irregularly distributed through the rock over a thickness of about 35 feet.

Operations on this very interesting deposit have been suspended, from which it is concluded that subsequent exploratory work did not bear out the high expectations originally formed of it.

Occurrence on the Property of the Northern Transvaal (Messina) Copper Exploration Company.—In sinking the No. 5 Shaft on this property, situated about 4 miles west of Messina in the Northern Transvaal, there was struck a sill of norite which, on assay, was found to contain appreciable amounts of platinum metals. Selected samples were found to average 3.1 dwts. and a dump sample from 0.4 to 1.5 dwts. The age of the norite cannot be fixed, but it intersects ancient gneiss and gneissic granite belonging to the Basement Series.

From our point of view special interest attaches to this occurrence because it lies at the very middle of the hypothetical Platinum Canal.

Occurrence on Preezburg, No. 102, North-north-west of Potgietersrust.—There is also complete uncertainty as to the age of a platinum occurrence situated on the farm named, some 55 miles north-north-west of Potgietersrust in the Transvaal.

Here platinum is found in a rather coarse-grained quartz-gabbro building a conspicuous hill. Assays of up to 3.5 dwts. were recorded. The gabbro consists of diallagic augite and plagioclase accompanied by a good deal of interstitial micropegmatite. Accessories include biotite and magnetite.

Occurrences in Southern Rhodesia.—According to Thomas and MacAlister¹ some Southern Rhodesian serpentines have

¹ *The Geology of Ore Deposits*, London, 1909, p. 54.

yielded chromite and picotite with traces of platinum. Zealley¹ is of opinion that the Selukwe chromite is referred to. An analysis made at the Imperial Institute of a sample of chromite from Selukwe showed 0.17 per cent. of copper and nickel oxides and a trace of platinum.²

Occurrence in Quartz Vein in the Old Granite.—Small amounts of platinum have been found in a quartz-specularite vein on the farms Doorn River, No. 923, and Frischgewaagd, No. 201, situated 15 miles south of Marabastad in the Northern Transvaal. The country rock is old Grey Granite, but there is no means of fixing the age of the vein. There is thus complete uncertainty as to the date of the mineralisation, and as to where this vein should be placed in our classification. Metals of the platinum group are also said to occur with gold in the ore of the Old Sheba Queen and some of the adjoining mines in the Barberton District, Transvaal.

¹ *Trans. Geol. Soc. S. Africa*, 1914, p. 64.

² *Bull. Imp. Inst.*, 1907, v., p. 137.

CHAPTER V

PLATINUM METALS IN THE GOLD-BEARING CONGLOMERATES OF THE WITWATERSRAND SYSTEM AND BLACK REEF SERIES

ON the Witwatersrand, as is well known, gold occurs as a constituent of very persistent beds of quartzitic conglomerate belonging to the system of rocks that bears its name. The conglomerate is popularly known as "banket," the Dutch name for an almond confection, which the weathered rock rather remotely resembles.

Conglomerates occur on a number of horizons in both the lower and upper divisions of the Witwatersrand System. All these conglomerates, popularly referred to as "reefs," are auriferous to a greater or less degree, gold being of very widespread occurrence in the system. So far only those belonging to the Main Reef zone and certain sectors of the Kimberley Reef and Bird Reef zones have proved worthy of exploitation on a big scale. It should be stated, however, that notable amounts of gold have also been won at different localities from conglomerates belonging to the Livingstone and Government Reef zones.

The Conglomerates of the Main Reef Zone.

Much the greater part of the huge output of the fields has been derived from the conglomerates of the Main Reef zone. These are being worked over an almost continuous stretch of 70 miles, at depths ranging from a few feet to over 7400 feet in the world's deepest mine, the Village Deep, Limited, situated south of Johannesburg.

As developed on the Central Witwatersrand the Main Reef zone contains three well-defined bands of conglomerate interbedded with quartzite and a thin bed of chloritoid

slate. The three conglomerate bands in descending order are:—

- (1) the South Reef;
- (2) the Main Reef Leader;
- (3) the Main Reef.¹

The "reefs" range in thickness from an inch and less to 15 feet, and the average tenor of the ore milled is about 6.8 dwts. per short ton.

It is only in the more central portion of the Witwatersrand goldfield that the Main Reef, Main Reef Leader and South Reefs are equally well developed. Proceeding westward the Main Reef Leader gives out at the Vogelstruis Estate, situated 11 miles west of Johannesburg, so that on the Far West Rand only the Main Reef and South Reef are represented, the latter often by a single line of pebbles or a mere parting plane.

Toward the east, on the other hand, both the Main Reef and South Reefs give out in the neighbourhood of Boksburg; and on the Far East Rand, whence the bulk of the Rand gold production now comes, the Main Reef Leader alone remains. It rests directly on a thick bed of quartzose slate. The existence of the metals of the platinum group in these, the greatest of all fossil placers, was first established by the late William Bettel who, in 1892, succeeded in extracting iridosmine (*sic*) and also platinum from "black sands" derived from the concentration of the banket of the "4-inch" Leader (Main Reef Series) of the New Rietfontein Mine.²

Subsequently, A. F. Cross noted the presence of the platinum metals in the *banket* of the New Modderfontein and East Rand Proprietary Mines, and also in conglomerates belonging to the Elsburg Series at the Old Steyns Estate Mine (13).

The first actual description of iridosmine from the banket was given in 1907 by R. B. Young (9), the material examined having been obtained from the New Rietfontein Mine. In 1912 C. B. Horwood published further particulars about the iridosmine of the New Rietfontein Mine (14). He also called attention to the occurrence of metals of the platinum group in

¹ The Main Reef is in places underlain at a distance of from 50 to 80 feet by the so-called North Reef, and the South Reef is similarly underlain in places by what is known as the Middle Reef. Neither has any economic significance.

² Cf. *S. A. Min. Journ.*, 1906, 10th November.

the Randfontein Mines, and predicted that minute amounts of these metals would be found throughout the conglomerates of the Main Reef Series. Subsequent investigations have confirmed this view. It was, however, only when amalgamation was abandoned in favour of preliminary concentration on corduroy and blankets that the recovery of these metals on a large scale became practicable. This change in the method of recovering the free gold present in the conglomerates was introduced in 1922. It has now been made on most of the larger mines and "osmiridium" extraction has become an integral part of the dressing operations. What is actually recovered is a concentrate containing several distinct minerals, probably including native platinum. In addition to the platinum minerals, grains of gold are rarely absent, and sometimes quite abundant.

The recovery of the "osmiridium" has, as already stated, become an important auxiliary of gold winning on the Witwatersrand. The output and sales for 1927 were as follows:—

Source of Production.	Output (Ounces).	Sales.	
		Ounces.	Sterling.
Witwatersrand :—			
Large Mines	5056.300	5211.845	54,431
Metallurgical Works	416.224	432.105	3,610
Heidelberg	...	9.230	96
Totals	5472.524	5653.180	58,137

The average price realised was £10.284 per ounce, as compared with £15.210 in the previous year.

The 5653.18 ounces of "osmiridium" concentrates sold contained:—

Metal.	Fine Ounces (troy).
Osmium	1724.902
Iridium	1601.031
Ruthenium and Rhodium	763.879
Platinum	606.939
Gold	147.942
Balance (undetermined)	808.487
Total	5653.180

The output for 1928 was 5670·637 ounces. There were actually sold 5913·453 ounces, which realised £85,692.

The major portion of the output is derived from the conglomerates of the Main Reef Series, the Main Reef Leader, as developed on the Far East Rand, being the principal source of production. Notable amounts are, however, also being recovered from the Kimberley or Battery Reef on the West Rand, and "osmiridium" has been proved to be present in conglomerates belonging to the Elsburg Series.

Distribution of the "Osmiridium."—As to the distribution of the "osmiridium" in the conglomerates of the Witwatersrand System, milling operations on a huge scale have definitely established that it is most abundant on the Far East Rand where the Main Reef Leader is being worked, less abundant on the West Rand where the Main Reef and South reefs are mined, and even less abundant on the Central Rand where all three beds of conglomerate are developed.¹ On the Far East Rand the principal producers in order of their productivity are the Government Gold Mining Areas, New Modderfontein, Modderfontein B, Brakpan and Modderfontein Deep Level Mines.

The distribution of "osmiridium" in any particular area of gold-bearing conglomerate has been proved in several mines on the Far East Rand, like the gold, to go with the big pebbles, and its distribution in other respects also corresponds closely with that of the gold. Further, tests on the Modderfontein East and Modderfontein "B" Mines have proved that banket rich in gold contains much more "osmiridium" than banket poor in gold. According to the sedimentary theory of origin of the gold, which is now generally accepted, this simply implies that the conditions favourable to the mechanical concentration of the gold were also favourable to the concentration of the "osmiridium," as would be expected from the close correspondence in their specific gravities.

It cannot be too strongly emphasised that even in the mines where it is relatively abundant the "osmiridium" constitutes only a vanishingly small proportion by weight of the *banket*. Thus on the Modderfontein "B," which is richer in "osmiridium" than any other mine on the Witwatersrand, the recovery during

¹ Cf. Lawn, J. G., "Presidential Address to Geological Society of South Africa," *Proc. Geol. Soc. S. Africa*, pp. xix-xxx.

1924 was only 1 ounce per 1212 tons of conglomerate milled. On the New Modderfontein Gold Mine it was 1 ounce per 1567 tons, and on Government Gold Mining Areas 1 ounce per 1973 tons. On the closely adjacent Van Ryn Deep Mine it was only about 1 ounce per 9285 tons. What proportion of the platinum metals actually present in the conglomerates is recovered is not known. Judging by the percentage recovery of free gold which is very carefully calculated, it is improbable, however, that on an average it is less than 50 per cent. It is, no doubt, different in different mines.

The figures given above will make it clear that the recovery of the platinum metals except as a by-product would be quite impracticable. Even as a by-product their commercial recovery is possible only because they are amenable to concentration by simple and cheap methods.

Nature and Composition of the "Osmiridium."—Two main varieties are, as already indicated, distinguished, namely, iridosmium or nevyanskite, which contains over 40 per cent. of iridium, and osmiridium or sysertskite, which contains less than 40 per cent. of iridium. Both varieties are apparently present in the Witwatersrand conglomerates, in which they occur in six-sided crystals for the most part tabular, in cleavage flakes and in flattened oval-shaped and rounded grains. The crystals are made up of combinations of the basal pinacoid and rhombohedra or pyramids. Their edges, as Young has pointed out, are invariably rounded. The crystals and grains of "osmiridium," which greatly predominate, are of dark-grey colour with a peculiar bronzy-red or bronzy-yellow sheen; their lustre is dull. The iridosmium, on the other hand, is characterised by a tin-white colour and splendid lustre. Between these extremes are grey and greyish-white varieties. It is thus probable that quite a series of iridium-osmium alloys are represented.

A sample of osmiridium concentrate from the Government Areas Mine, examined by the writer, was found to consist mainly of grains and crystals of osmiridium ranging from 0.04 to 0.16 mm. in diameter. They are accompanied by what are taken to be platy crystals of iridosmium up to 0.19 mm. across, and by cleavage flakes of that mineral. In addition there are present spherical and oval-shaped metallic particles of greyish-white colour. These are probably native platinum,

while small rough-looking pitted rounded grains of a dark-coloured unidentified metallic mineral probably represent metallic ruthenium or a natural alloy rich in that metal, the presence of considerable amounts of which in the concentrate is indicated by the analyses given below. In this connection it should be stated that practically the whole of the platinum and ruthenium proved by analysis to be present can be dissolved out by means of hot aqua regia, by which osmiridium itself is not affected. Apart from the minerals mentioned there were noted grains and octahedral crystals of chromite, crystals of zircon, and numerous small oval-shaped grains of gold. One such, with a maximum diameter of 0.14 mm., was found to enclose completely except on one side, where it projects, a crystal of osmiridium, 0.06 mm. in diameter. As it is generally agreed that the gold in the Witwatersrand Conglomerates has undergone solution and reprecipitation this interesting and unique specimen has no special genetic significance.

Chemical Composition—Chemical analyses of a number of typical samples of the osmiridium concentrate are given in the following table. The first three were placed at the writer's disposal by Mr F. W. Watson of the Rand Mines Laboratory. In addition to the metals named traces of palladium are also sometimes found.

Analyses of "Osmiridium" Concentrate.

Name of Mine.	I. Modderfontein B.	II. City Deep.	III. Knight Central and Wolluter (mixed).	IV. Government Areas.
Ir	28.12	29.02	34.71	35.78
Os	32.72	37.11	39.26	39.71
Ru	15.12	12.45	11.28	9.60
Pt	11.44	8.41	7.00	6.12
Rh	0.46	0.19	0.22	0.16
Au	0.27	4.10 ¹	0.07	0.39
Total . .	88.13	91.28	92.54	91.76

¹ This is evidently gold left in the concentrate by accident or oversight.

The balance is insoluble gangue.

I.-III.—Analysed by D. C. Griffith & Co., London.

IV.—Analysis quoted by J. G. Lawn, *loc. cit.*

The average composition of the "osmiridium" produced on the Witwatersrand during 1927 was as follows:—

Metal.	Per Cent.
Osmium	30.51
Iridium	28.32
Ruthenium and Rhodium	13.51
Platinum	10.74
Gold	2.62
Balance (undetermined)	14.30
Total	100.00

The maximum and minimum percentages of the individual components, taking the "osmiridium" from the big mines of the Witwatersrand fields, were as follows:—

Metal.	Minimum Percentage.	Maximum Percentage.
Osmium	24.82	41.36
Iridium	22.07	36.55
Ruthenium and Rhodium	10.29	15.41
Platinum	4.48	15.70
Gold	0.01	12.64

It has already been suggested that the large amounts of platinum and ruthenium proved by these analyses to be present are contained in the two minerals described. This, however, is largely surmise and remains to be confirmed by farther chemical and mineragraphic investigation.

Genesis of the "Osmiridium."—The "osmiridium" and allied minerals are without doubt of contemporaneous deposition with the conglomerates. As Young (10) has pointed out, there are all gradations from crystals with slightly worn edges to completely water-worn grains. It is also quite clear that unlike the gold these minerals did not undergo solution and recrystallisation, but are in the condition in which they were originally deposited—a remarkable tribute to the great stability of the platinum group metals.

While there cannot as yet be said to be any general agreement as to the precise manner in which the gold-bearing conglomerates were laid down, geologists are unanimous in their support of Mellor's view that the materials of which they

are composed were brought down from the north-west or north-north-west by one or more rivers that discharged into a great delta on or near the site of the present Witwatersrand. These rivers evidently carried to their ultimate resting place the minute crystals and grains of "osmiridium" and related minerals that are now, after having for years baffled the ingenuity of the metallurgical engineer, being successfully extracted from the *banket*.

Available Reserves in the Witwatersrand Conglomerates.

The total quantity of "osmiridium" locked up in the conglomerates of the Witwatersrand System must be large. The available reserve, however, is limited, because, as we have seen, it will never be possible to recover it except as a by-product of gold mining, and the very considerable amounts that have in the past found their way into the vast sand and slime dumps are also irrecoverable.

The output will thus necessarily be strictly proportional to the output of gold and, in particular, to that of the mines working on the more productive section of the Far East Rand, where the bulk of the "osmiridium" comes from. It has already been stated that during the year 1928, there was sold "osmiridium" to the value of over £85,000. Provided that the prices of iridium and osmium are maintained at their present level, it will probably remain at roughly that figure for years to come, as there is no prospect in the near future either of any marked increase or decrease in gold production on the Far East Rand. The output will eventually decrease *pari passu* with the decline in the gold production of that area.

"Osmiridium" in the Black Reef.

The basal member of the Transvaal System, the Black Reef conglomerate, carries profitable amounts of gold in places in irregular shoots and patches. That the gold is accompanied by metals of the platinum group was established in the Klerksdorp district as early as 1888. More recently the conglomerate has been found in certain areas to carry notable amounts of "osmiridium," as, for example, at the old Vesta Mine to the south-west of Johannesburg, and in the Machavie Mine in the Klerksdorp district.

Assay values as high as 20 dwts. per ton have been reported

from the footwall of the "reef" in these mines, but it is difficult to get reliable information. A sample, recently submitted to the writer from a mine on the Black Reef, which was claimed to be very rich in osmiridium, returned on assay 0.70 dwt. of platinum metals per ton. Active prospecting for "osmiridium" is at present in progress at a number of mines and properties on the Black Reef. The only actual production so far recorded is by a small worker washing the dumps of the old Orion and Minerva Mines on the Black Reef near Natal Spruit south of Johannesburg. The output from this source amounted in 1924 to 21.31 ounces valued at £376.

CHAPTER VI

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX

The Bushveld Igneous Complex.

THE Bushveld Igneous Complex is a vast composite body of plutonic and volcanic rocks¹ occupying an area of about 15,000 square miles in the central part of the Transvaal (Plate XXXVI.). It is irregularly oval in ground plan. The longer axis of the oval, which is directed from east-north-east to west-south-west, has a length of 280 miles, and a maximum width of 150 miles.

The Complex consists in its outer or lower portion of norite and allied basic and ultrabasic rocks, and in its central or upper portion of red granite, granophyre, basalts, and pyroclastic volcanic rocks.

The norite, with which we are more particularly concerned, forms a great basin-shaped sheet or lopolith from 2 to 3½ miles in thickness, the width of the outcrop ranging from 5 to 12½ miles. This immense sheet was intruded in pre-Waterberg times in the upper part of the Pretoria Series,² and conforms fairly closely to the strike and dip of the rocks of that series, being everywhere inclined inward toward the heart of the Complex at from 5 to 50 degrees. It is probable, as originally suggested by Molengraaff,³ that at the time when the intrusion took place the sedimentary rocks were still horizontal or nearly so, and only assumed their present basin-like disposition long subsequently as a result of the gradual subsidence or sagging of the floor due to the enormous load of overlying igneous rocks.

The writer has pointed out elsewhere (26) that the great basin occupied by the norite consists of two distinct portions, namely, a main or *deep eastern portion* extending from the

¹ Cf. Hall, A. L. (8 and 8A); and Daly, R. A., and Molengraaff, G. A. F., *Journ. Geol.*, 1924, pp. 1-35. Dr A. L. Hall has in preparation a comprehensive memoir on the Bushveld Igneous Complex.

² The sedimentary rocks of the Rooiberg Series, which, over wide areas, form the roof of the great sheet, are here taken to constitute the uppermost part of the Pretoria Series.

³ *Geology of the Transvaal*, p. 57.

neighbourhood of Lydenburg to just west of the Pilandsberg, and a subsidiary or *shallow western portion* in which a number of great inliers of quartzite and altered shale project island-like from the igneous rocks. The latter forms, as it were, a lip-like extension of the main basin toward the west. There is also an important lip-like extension of the norite zone north-north-west of Potgietersrust. These two extensions are fundamentally different in character. In the western extension, west of the Pilandsberg, only the lowermost part of the norite zone is represented; the upper part is missing altogether. In the Potgietersrust extension the lower part is missing.

The comparative thinness of the norite in the western extension is due to denudation consequent on the comparatively high elevation of the sedimentary floor relatively to that east of the Pilandsberg, the relation of the norite to the underlying rocks of the Pretoria Series being a concordant one. In the extension north-north-west of Potgietersrust, on the other hand, the thinness of the norite is due to an abrupt shallowing of the Bushveld Basin in this direction. It will also be pointed out subsequently that the upper part of the norite sheet here cuts diagonally downward across the underlying rocks of the Transvaal System, so that it is floored by progressively lower horizons until it is in direct contact with the Old Granite. We have thus an example of what A. L. Hall (8) calls "an intrusive transgression." A diagrammatic section showing the probable relation of the norite in this area to the underlying and overlying rocks is given in Fig. 25.

The differences between these two extensions have been emphasised because they have an important economic significance. As a consequence of the great denudation that has taken place in the western extension, the Merensky Platinum Horizon, to which detailed reference will be made, is here missing, having been completely swept away, while it attains a very important development in the Potgietersrust extension. The Merensky Horizon, it should be stated, completes the circuit of the main Bushveld Basin, detached outcrops being found immediately west of the Pilandsberg (Plate XXXVI.).

The composition of the great norite sheet, as might be expected, is not everywhere the same. In some areas, such, for instance, as that immediately north of Pretoria, the lower part

PLATE V



1. Pseudo-stratification in anorthositic norite overlying Merensky Platinum Horizon on farm Driekop, No. 170, Lydenburg district.



2. Pseudo-stratification in bronzitite west of Pilansberg, Transvaal.



of the zone, like the upper part, shows very little differentiation. As a rule, however, the lower part is marvellously differentiated. Within it lenses and sheets of the most diverse rocks succeed one another with bewildering rapidity. The following are some of the principal types represented: norite, pyroxenitic norite, pseudo-porphyrific diallage-norite, bronzitite, harzburgite or bastite-serpentine derived from it, chromitite, and anorthosite of several kinds. These diverse rocks constitute what has been termed the Differentiated¹ or Critical² Zone. This rests either directly on what Hall has termed the *Basal* or *Chill Phase* of fine-grained diabasic norite which everywhere occupies the lowermost part of the lopolith, or on the *Transitional Zone* of Hall by which the Basal Zone is overlain in some areas; the *Traditional Zone* consisting of basic bronzite-norite with narrow zones of dark pyroxenite.

Overlying the Differentiated Zone is a very considerable thickness of even-grained diallage-bronzite-norite, showing very little differentiation except in its uppermost portion where it encloses great stratiform segregations of titaniferous iron-ore associated with bands of labradorite-anorthosite. This great zone of predominantly undifferentiated norite is referred to by Hall as the *Main Belt*. It makes up one-half, and in places more than one-half of the entire thickness of the norite zone. It, in turn, is overlain by Hall's *Upper Zone*. This consists of diallage-norite which, as the roof of the Complex is approached, is succeeded by more leucocratic, gabbroitic, and syenitic types. A composite section across the norite lopolith south-west and south of the Pilandsberg shows³ the following succession. It should be studied in connection with the section of Plate XXXVII. and with Fig. 20. It will be noted that the Transitional Zone which, in the Lydenburg district, attains a very considerable thickness, is here not developed.

Pseudo - Stratification. — Perhaps the most remarkable feature of the Norite Zone is the manner in which the rocks composing it are pseudo-stratified. They behave, particularly in the lower portion, exactly like evenly bedded sediments, their dip and strike, which everywhere exhibit the utmost regularity, conforming to those of the underlying rocks of the Pretoria Series. Geologists unacquainted with this peculiarity of the Bushveld Complex always express astonishment at

¹ Cf. Wagner (26). ² Cf. Hall (8 and 8A). ³ Cf. Wagner (26), p. 31.

Composite Section across Norite Lopolith South-West and South of the Pilansberg.

Composite Section across the Dorsal, Lower West and South of the Pilansberg.			
			Approximate Thickness in Feet.
<i>Upper Portion, south of the Pilansberg</i>	<i>Upper Zone</i>	Norite, graduating upward into gabbro and syenite.	...
	<i>Main Belt</i>	{ Diallage norite with stratiform segregations of titaniferous magnetite and labradorite-anorthosite.	Magnetite Horizon
		{ Diallage norite.	
<i>Lower Portion, south-west of the Pilansberg</i>		{ Diallage norite.	...
		{ Bronzite with bands of anorthosite and pseudo-porphyrific diallage norite.	Merensky Platinum Horizon ¹
		{ Bronzite with seams and lenses of chromitite.	Chromitite Horizon
		{ Bronzite with isolated lenses of harzburgite and differentiated diallage norite.	...
	<i>Differentiated or Central Zone</i>	{ Bronzite with lenses of harzburgite and anorthositic norite containing bands of bytownite-anorthite and labradorite-anorthosite.	Vlakfontein Nickel Zone
		{ Bronzite with lenses of harzburgite.	...
		{ Pyroxenitic olivine-norite probably graduating downward into the	...
		<i>Basal or Chill Zone of diabasic quartz-norite.</i>	400
Combined maximum thickness			15,100

¹ The Merensky Horizon is not exposed in this section, but has been opened up a few miles to the north in the position indicated.

seeing rocks such as bronzitite, anorthosite, and norite behaving as though they were regularly stratified sandstones and limestones. The Merensky Platinum "Reef" is particularly noteworthy in this respect, its regularity both as to strike and dip being in some areas almost uncanny. Thus, boreholes put down on the farms Kroondal and Klipfontein near Rustenburg at a distance of 2000 feet from the outcrop, intersected the "reef" within a foot of the estimated depth; while on the farm Swartklip, also in the Rustenburg district, a line of prospecting pits laid out over a distance of 13,000 feet along the presumed line of strike all struck the "reef" with the exception of one.

So regular and persistent are the individual tabular bodies of rock that it becomes possible to distinguish widespread igneous zones and horizons in the great lopolith, quite as well defined as are the zones and horizons in a succession of sedimentary strata. The writer was the first (25, 26, and 28) to apply these terms to the chromite, magnetite, and platinum deposits of the Bushveld Complex, and their use has since become general.

The Differentiated Zone.—The Differentiated Zone is by far the most interesting of the several zones discriminated. It is also the most important from the economic point of view, in that the important platinum, nickel, and chromite deposits of the Bushveld Complex are contained in it.

It presents a number of perplexing problems. In the first place the question arises: why are some sectors of the lower part of the Norite Zone so marvellously differentiated while others show very little differentiation? This has been attributed elsewhere¹ to the unequal distribution of sulphur in the portion of magma that gave rise to the lower part of the Norite Zone. It is becoming increasingly apparent that sulphur, probably appearing in magmas as H_2S or as an alkaline sulphide such as Na_2S , is a powerful mineraliser. Now magmatic sulphides and concentrations of such sulphides are present in the Bushveld Complex only in those sectors of the Norite Zone that show pronounced differentiation. It is reasonable to infer, therefore, that the differentiation was brought about by the presence of abnormal amounts of sulphur in particular magma fractions. In consequence, these were kept in a fluid state for a longer period than would otherwise have been the case, thus leading to far-reaching magma splitting. The theory is

¹ Wagner (26).

supported by the fact that the world over norite and gabbro masses containing magmatic sulphide deposits are characterised by extreme differentiation.¹

As to the remarkable heterogeneity of the zone and the recurrence of the same types of rock on widely separated horizons, the writer² has put forward the view that the Differentiated Zone owes its origin to a process of stratiform segregation brought about by intermittent crystallisation-differentiation, the intermittency being attributed to periodically recurring checks in cooling due to a rise of the isogeotherms during consolidation, caused by spasmodic subsidence of the floor of the lopolith.³ A more detailed study of certain sections of the zone has, however, convinced him that, even if such intermittency of cooling can be postulated, simple crystallisation-differentiation⁴ is not adequate to account for the observed

¹ Cf. Howe, Ernest, *Econ. Geol.*, 1925, pp. 330-334; Rogers, A. W., *Proc. Geol. Soc. S. Africa*, 1916, p. xxi., and Tolman and Rogers (90).

² Wagner (26, pp. 77-87).

³ It should be stated that this theory of differentiation *in situ* is opposed by E. Reuning (59) who favours the view that what has here been termed the *Differentiated Zone* is due to the injection, as successive sills, of a large number of magma fractions of varying composition that originated in the lower part of the Bushveld hearth. This multiple sill hypothesis has so far found no other adherents, and is not even seriously considered by authorities such as A. L. Hall (8 and 8A). The chief arguments against it are: (1) That some of the presumed sills have been found by careful mapping to be elongated lenses completely enclosed in other rocks, without any trace of the cutting bands or dyke-like bodies that could have served as feeders; and (2) that, while they are as a rule sharply defined, gradations are often observed between the rocks taken to represent the successive intrusions. Thus, the Merensky "Reef," which Reuning singles out as an example of a sill, is in places seen to merge by imperceptible gradations into the hanging-wall norite. Chromitite is seen to graduate through chromite-bronzitite into bronzitite, and anorthosite through anorthositic norite into norite.

Yet another explanation which was tentatively suggested to the writer by Professor E. Kaiser, of Munich, is that the very persistent sheets and layers of rock composing the Differentiated Zone may have arisen by a process of selective replacement, operating on a gigantic scale, of sedimentary rocks by igneous material. When one attempts, however, to visualise a process of selective replacement that could give rise, for instance, to a layer of marble-like anorthosite occurring in direct contact with a seam of chromitite, there are such enormous difficulties in the way of this hypothesis that it cannot be seriously entertained.

⁴ Cf. Bowen, N. L., *Journ. Geol.*, 1917, p. 209, and 1919, p. 393.

phenomena. For instance, there are present in the Differentiated Zone very considerable thicknesses of rock, such as mottled anorthositic norite, characterised throughout by poikilitic texture, the outstanding feature of which is that big homogeneous crystals of diallage play the rôle of matrix for small crystals of bronzite and labradorite, while big anhedral labradorite play the rôle of host for crystals of bronzite. The writer fails entirely to see how the accumulation under the influence of gravity of early formed crystals could give rise to such bodies of rock.

As an alternative to the hypothesis of Bowen we have that of J. H. L. Vogt.¹ According to this, early formed crystals, settling under the influence of gravity, are redissolved in the underlying magma, giving rise to proto-enriched magma fractions which, on consolidation, crystallise as anchi-monomineralic rocks. Vogt's hypothesis would more readily account for the features presented by the Differentiated Zone. It is quite conceivable, therefore, that in the consolidation of the great norite sheet both this process and ordinary crystallisation-differentiation may have been operative. Here, however, we are entirely in the realm of speculation, and we must conclude this section by admitting reluctantly that no adequate explanation can at present be given of the remarkable features presented by the Differentiated Zone of the Bushveld Complex.

Having now dealt briefly with the geology of the Norite Zone and with some of its problems, we may proceed to discuss the remarkable platinum deposits that have been opened up in it during the past five years.

The Platinum Deposits.

These are as numerous as they are varied, and spread over an enormous area. The accompanying map (Plate XXXVI.) shows the localities of the deposits so far discovered. It will be seen that the distance between the extreme points at which the platinum has been found, measured along the periphery of the Norite Zone, is over 400 miles.

With regard to their distribution, the only generalisation that can be made at present is that the economically important

¹ Cf. "The Physical Chemistry of the Magmatic Differentiation of Igneous Rocks," *Journ. Geol.*, 1921, Nos. 4, 5, 6, and 7.

platinum deposits are confined to those parts of the Norite Zone in which there is evidence of very considerable magma splitting. This proves at the outset that pronounced differentiation is an essential for the magmatic concentration of platinum, a conclusion that is amply borne out by such detailed studies as have been made of the individual occurrences.

The deposits present extreme diversity as to their nature, as will be apparent from what follows.

Adequately to describe deposits so numerous, so widely separated and so varied, some scheme of classification is necessary. Several suggest themselves. Thus, the deposits might be arranged or classified "stratigraphically," according to the horizon which they occupy relatively to the floor and roof of the norite lopolith. This scheme would be admirably adapted to the deposits in the western part of the Lydenburg district, where notable concentrations of platinum have now been found on no fewer than eight distinct horizons. As, however, the lopolith shows in different areas considerable differences in thickness and in the nature and succession of the rocks composing it, such a classification, if applied to the whole of the great intrusion, might prove misleading. To classify the deposits geographically according to the district in which they occur and the horizon of the Norite Zone which they occupy would also be unsatisfactory, as this would involve treating separately of deposits that are identical in every respect. Open to the same objection would be a classification based on the mode of origin of the deposits and of the rocks with which they are associated, as this would mean in some instances the separate treatment of different parts of the same deposit.

As all three schemes are thus in themselves unsatisfactory, the writer has endeavoured to combine them in the following classification of the deposits in and connected with the Norite Zone. This, while it still has some of the defects above referred to, has the great advantage that it shows at a glance the nature and mode of origin of the different types of deposit, and, if it be remembered that the dunite and chromitite occurrences are confined to the lower part of the lopolith, it also shows their spatial relations.

The several types of deposit will be treated seriatim as far as it is practicable and convenient to do so, beginning with the dunite deposits.

Classification of the Platinum Deposits of the Norite Zone of the Bushveld Igneous Complex.

- C. *Pneumatitic Deposits* formed by indirect segregation from the parent norite magma . . . (8) Deposits in acid quartz-bearing differentiates of the norite magma.
- (7) Deposits of the Blaauwbank type in which the ore-bearer is quartz-bearing anorthositic norite.
- (6) Deposits of the Steelpoort Park type in which the ore-bearer is a medium-grained felspar-rich spotted norite.
- (5) Deposits of the Minsk's Claims type, Lydenburg District, in which the ore-bearer is a rather coarse-grained felspar-rich diallage norite.
- (4) Deposits of the Merensky Horizon type occurring above and below the main horizon in the Lydenburg District.
- (3) Deposits of the Merensky Horizon type as developed in the Rustenburg, Pretoria, Lydenburg, Pietersburg and Potgietersrust districts; the ore-bearers are pseudomorphitic pyroxenitic diallage-norite, felspathic pyroxenite, felspathic harzburgite and chromitite.
- (2) Deposits of the Twefontein type (Potgietersrust District) in which the ore-bearer is a fine-grained pyroxenitic diallage-norite, merging into coarse-grained felspathic bronziite and bronziite.
- (1) Deposits of the Vlakfontein type (Rustenburg District) in which the ore-bearer is bronziite.
- (a) In the Upper Part of the Norite Zone
- (b) In the Lower Part of the Norite Zone
- III. Deposits in which platinum is associated with magmatic nickel-copper-iron sulphides in norite, pyroxenite and harzburgite.
- II. Chromitite Deposits.
- I. Olivine-dunite deposits.
Iron-rich olivine-dunite deposits.
Hortonolite-dunite deposits.
- A. *Orthotectic Deposits* formed by direct segregation from the parent norite magma.
- B. *Contact-Metasomatic Deposits* in altered dolomite or sheared banded ironstone directly underlying platinum-bearing norite or pyroxenite.

CHAPTER VII

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

Dunite Deposits.

THESE deposits are of exceptional interest. While it was assumed at first that the rather abnormal hortonolite-dunite alone carries platinum in notable quantities, more recent investigations by the writer have shown that there are represented, in addition to the hortonolite-dunite occurrences, olivine-dunite deposits identical with those of the Urals, and deposits where platinum is found in dunite and wehrlite composed predominantly of iron-rich olivine.

These latter are intermediate in character between the normal Uralian platinum deposits and the hortonolite-dunite deposits of the Lydenburg district.

From the genetic point of view they also provide a link between the two types of deposits. There is, as will be shown, fairly clear evidence that in the formation of the deposits in which platinum is associated with iron-rich olivine, differentiation did not go quite so far as in the hortonolite-dunite deposits, owing to lack of mineralisers.

As a preliminary to the description of the deposits it will be useful to refer briefly to the classification and nomenclature of the minerals of the olivine group.

The term *olivine*, by general consent, is applied to mixtures of forsterite and fayalite having the constitution: $n \text{ Mg}_2\text{SiO}_4 + \text{Fe}_2\text{SiO}_4$, where n varies from 12 to 2.

The name *hyalosiderite* is applied by some mineralogists to all varieties containing more iron than is demanded by this formula. Hintze¹ and Doelter,² however, rightly point out that the name was introduced by Bauer³ to designate olivine in which the ratio of Mg_2SiO_4 to Fe_2SiO_4 is approximately as 2 : 1,

¹ *Handbuch der Mineralogie*, vol. ii., p. 22.

² *Handbuch der Mineralchemie*, vol. ii., p. 312.

³ *N. Jahrb. f. Min.*, 1889, vol. i., p. 1.

and should only be applied to varieties of the mineral having that composition.

Following Brush¹ and Warren,² these authors use the term *hortonolite* for varieties in which FeO and MgO are present in approximately equal proportions, and Doelter³ suggests that it should be used for all olivines having the composition $n \text{ Fe}_2\text{SiO}_4 + \text{Mg}_2\text{SiO}_4$ where n varies from 1 to 2.

Varieties richer in iron may be designated *fayalite*.

It will be shown that in the olivine of which the dunite of the occurrences on Onverwacht, No. 330, and Mooihoek, No. 147, is mainly composed, the molecular ratio of FeO : MgO is very nearly 1 : 1. It is thus hortonolite in the strict acceptance of the term.

A low manganese content appears to be characteristic of olivine of this composition. The hortonolite of Monroe, New York, described by Brush, contained no less than 4.35 per cent. of MnO, and that of Cumberland, Rhode Island, described by Warren, contains 1.5 per cent. According to the analyses of the Onverwacht and Mooihoek hortonolite-dunite, presently to be given, the hortonolite of the former contains approximately 0.4 per cent. of MnO and that of the latter 1 per cent.

The olivine of the iron-rich facies of the platinum-bearing dunite on Driekop, No. 170, is not hortonolite, but olivine in which, as will be shown, the ratio of MgO to FeO is roughly as 2.4 : 1. It may thus be described as iron-rich olivine, approximating in composition to hyalosiderite.

In the olivine-dunite of Mooihoek, which is also in part platinum-bearing, the ratio of Mg_2SiO_4 to Fe_2SiO_4 is roughly as 9 : 2. The olivine of Onverwacht appears to have much the same composition. It is of interest to record that according to Duparc and Tikonowich (22) the olivine of the platinum-bearing dunites of the Ural Mountains ranges in composition from 8 Mg_2SiO_4 : Fe_2SiO_4 to 11 Mg_2SiO_4 : Fe_2SiO_4 .

Classification of the Dunite Deposits.—Adopting the scheme of classification of olivines given above, the dunitic platinum occurrences of the Bushveld Complex may be classified as follows :—

- (I.) Occurrences in iron-rich dunite (Bushveld type), and
- (II.) Occurrences in normal olivine-dunite (Uralian type).

¹ *Am. Journ. Sci.*, 1896, vol. xlviii., p. 19.

² *Z. f. Kryst.*, 1907, p. 213.

³ *Loc. cit.*, p. 720.

The occurrences in iron-rich dunite may again be subdivided into:—

- (a) Hortonolite-dunite deposits, and
- (b) Deposits in which platinum occurs in association with iron-rich olivine approximating to hyalosiderite in composition.

I.—Hortonolite-Dunite Occurrences.

In these, where platinum-bearing, that metal occurs in pipe- or parsnip-shaped segregations and smaller veins and lenses as a primary constituent of hortonolite-dunite and rocks associated with it.

Over sixty separate occurrences of hortonolite-dunite have been discovered in the lower part of the Norite Zone in the Lydenburg and Rustenburg districts. So far only two have been found to be worthy of exploitation. These are the occurrences on Mooihoek, No. 147, and Onverwacht, No. 330, situated in the Lydenburg district in close proximity to each other. By a remarkable coincidence, they were also the first to be found. The other occurrences of hortonolite-dunite are all either barren of platinum or contain only traces of the metal.

The very interesting Driekop "Pipe," which is also being worked on a big scale, is not, as was originally believed, a hortonolite-dunite deposit, but an example of the occurrence of platinum in segregations of iron-rich dunite and wehrlite.

There is no definite Hortonolite-Dunite Horizon as Dr Mellor and the writer (29) originally assumed. While the workable deposits above referred to lie, as elsewhere stated, between the upper and lower chromite horizons in the lower part of the Norite lopolith, the known occurrences cover a vertical range of quite 2000 feet in the lower part of the Norite Zone, some of those in the southern part of the Lydenburg district being situated above the Merensky Horizon. All that can be said about them is that they are confined to the Differentiated or Critical Zone already referred to.

There are two main types of hortonolite-dunite deposit. In one of them the hortonolite-dunite forms pipe- or parsnip-shaped segregations, lenses, and patches in olivine-dunite or serpentine derived from it. In the other, the dunite forms irregular sheets, lenses, and schlieren in coarse pegmatitic diallagite or diallage-ilmenite-pegmatite.

PLATE VI



1. Scenery on the northern part of Rustenburg platinum fields. In foreground, great open plains underlain by lower part of norite zone. In background, isolated hills and broken ridges marking position of the "Main Belt."



2. Typical scenery on Lydenburg platinum fields. View looking westward from Onverwacht Platinum Mine with the escarpment of the Lulu Mountains in the background.



In certain of the bigger occurrences, such as those on Mooihock, No. 147, both types of occurrence are present, namely, segregations in olivine-dunite and pegmatitic diallagite.

It should be stated that the enclosing rock, whether olivine-dunite or pegmatitic diallagite, exhibits, as a rule, a transgressive relation to the surrounding rocks of the Norite Zone. In this respect these occurrences introduced a new note into Bushveld geology. Until they were found it was generally assumed that all of the rocks entering into the constitution of the Norite Zone were definitely pseudostratified, and it was only when the Mooihock and Onverwacht "pipes" were opened up that

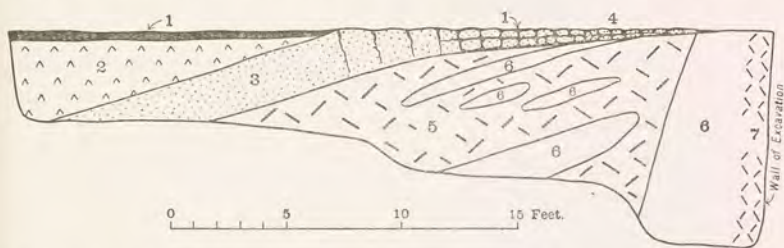


FIG. 2.—Section exposed on south wall of No. 3 Working, Boschfontein, No. 489, Rustenburg District. Shows bodies of hortonolite-dunite conforming to and cutting across pseudostratification.

- | | |
|---------------------------------------|--------------------------------|
| 1. Black Turf Soil. | 4. Chromitite Rubble. |
| 2. Pseudoporphyrific Diallage-norite. | 5. Pegmatitic Diallage-norite. |
| 3. Chromitite. | 6. Hortonolite-Dunite. |
| 7. Hortonolite-wehrlite. | |

it was found that they cut at right angles across the general pseudostratification. It must be added, however, that big sheets of hortonolite-dunite, associated with pegmatitic diallagite, and conforming to the pseudostratification, are also known. One such caps the high hills in the eastern part of Grootboom, No. 186, situated south of the Steelpoort River in the Lydenburg district. Good examples of smaller sheets and lenses of hortonolite-dunite are to be seen in a working on Boschfontein, No. 489, near Rustenburg (Fig. 2).

From the economic point of view the occurrences of hortonolite-dunite in olivine-dunite alone are important.

Petrography of the Hortonolite-Dunite.—The normal hortonolite-dunite everywhere presents much the same features.

It is of striking appearance and, once seen, is not easily

forgotten. In its typical development it is a dark, heavy, lustrous, phanocrystalline rock, weathering with a characteristic rust-like crust of brown and blackish-brown colour. On freshly broken surfaces the colour ranges from deep honey-brown in the oxidised zone, through greenish-brown to brownish-green in the deeper levels of the mines.

The grain of the rock is extraordinarily uneven. In hand specimens it always appears to be very coarse grained, sometimes exhibiting individual grains of hortonolite up to 6.23 cm. long and 2.5 cm. wide. Actually the large grains are, as a rule, found to be accompanied by small grains, and the average diameter of grain in the thin sections examined does not normally exceed 1.5 cm. In places, however, the grain is coarse throughout and the habit of the rock truly pegmatitic; big individuals of hortonolite being then usually accompanied by equally big or bigger individuals of hornblende, phlogopite, diallage or magnetiferous ilmenite.

The dunite has the distinction of being the heaviest igneous rock composed essentially of silicates that has so far been found, the specific gravity ranging from 3.752 to 3.83. In some of the chromite- and ilmenite-rich facies it exceeds 4.

The principal constituent, as already indicated, is hortonolite, with characteristic concoidal fracture and resinous lustre. This is accompanied by subordinate amounts of lustrous black hornblende, greenish-grey, brown-weathering diallage, brown phlogopite, lustrous magnetiferous ilmenite, magnetite, chromite, apatite, and sulphides (pyrrhotite, chalcopyrite, and chalmersite). In the strictly dunitic facies of the rock, the texture of which is allotriomorphic-granular, these minerals together make up less than 7 per cent. of the whole, so that it is to all intents and purposes monomineralic.

The mineralogical composition of a typical specimen from Onverwacht, No. 330, of which an analysis is given in column I of the table on page 60, was actually found to be as follows:—

	Per cent.
Hortonolite	93.20
Diallage	5.00
Hornblende	1.50
Chromite	0.25
Magnetite	0.05
Total	<u>100.00</u>

PLATE VII



1. Photomicrograph of platinum-bearing hortonolite-dunite on Onverwacht, No. 330. The whole field is occupied by hortonolite enclosing small crystals of chromite seen at centre of photograph. Black bands represent secondary limonite deposited along cleavage and other cracks in the hortonolite. $\times 21$.



2. Photomicrograph of hortonolite-dunite, same locality. Shows irregular grain of diopside surrounded by hortonolite. White is open field. $\times 18$.



Hornblende, diallage, phlogopite, and magnetiferous ilmenite are, however, locally abundant and present in bigger proportions than those indicated above. The hornblende, where abundant, occurs in big lustrous black prismatic individuals up to 6 and exceptionally even 15 cm. in length, holding poikilitic inclusions of phlogopite, the texture of the rock being always poikilitic where hornblende or diallage are abundant. The latter mineral is also sometimes seen in irregular individuals up to 6 cm. across.

The phlogopite occurs in books up to 2 inches in diameter and $\frac{3}{4}$ inch in thickness, and in irregular aggregates of such books up to a foot across. The cleavage planes of the mineral often show a beautiful iridescence. On weathering it assumes a pale bronze colour. It sometimes encloses prisms of greenish-grey apatite up to 1 cm. in length.

Magnetiferous ilmenite is locally very abundant in both the Onverwacht and Mooihoek "pipes." It occurs in irregular homogeneous individuals up to 12 cm. across, and also intergrown with hortonolite in local segregations of hortonolite-ilmenite up to 3 feet across (Analysis IV., page 60). Magnetite, in irregular dull-looking black grains up to 1 mm. across, is sometimes present in addition to the ilmenite.

Microscopic Characters.—In thin sections of the dunite the hortonolite is seen to occur in irregular grains with rounded contours. It exhibits a very distinct cleavage parallel to (010) and a less distinct cleavage parallel to (001). It generally encloses minute tabular interpositions arranged in irregular plates at right angles to one another, one set lying parallel to (100) and the other parallel to (001). The interpositions parallel to (001) are smaller and are seen under high powers of magnification to be made up of aggregates of minute closely spaced parallel plates. No definite clue was obtained as to the precise nature of these interpositions.

The hortonolite of the main Onverwacht occurrence has a refractive index β of 1.749 and a large axial angle. It is optically negative. That of the Mooihoek occurrence appears to be practically identical in its optical properties, with perhaps very slightly lower refractive indices.

The hortonolite, even at the outcrop, shows no sign of serpentinisation, but is traversed along cracks and cleavages by a network of thin translucent or opaque bands of deep brown

colour. These are found to consist of small ragged patches of secondary limonite and hematite ranging up to 0.1 mm. across. They evidently owe their origin to the conversion of part of the ferrous oxide contained in the hortonolite molecule into ferric oxide. This accounts for the fact that the analysis of the outcrop specimen of the rock shows nearly 3 per cent. of the latter constituent.

The same phenomenon has previously been recorded in the case of less ferriiferous olivines.

The microscope proves that two varieties of hornblende are present. These occur separately and also intergrown and rimming one another. One of them is almost colourless in thin sections and is evidently a variety of edenite. It forms hexagonal prisms up to 0.55 cm. in length which penetrate the hortonolite in ophitic fashion, proving that they crystallised before that mineral. It is very weakly pleochroic in shades of dull greenish-brown and greenish-yellow, and has an extinction angle of $18^{\circ} 30'$. The refractive index γ is very nearly equal to 1.4607.

The mineral appears to alter readily to an almost isotropic chlorite of pale-green colour. As a preliminary to this transformation it develops a confused fibrous structure. The chloritisation is accompanied by the deposition of secondary magnetite, so that altered grains of the hornblende are crowded with minute inclusions of that mineral.

The other variety of hornblende is that forming the big black anhedral visible in hand specimens. It is interstitial to the hortonolite and holds poikilitic inclusions of that mineral.

It is strongly pleochroic. The properties of this variety of hornblende, as developed in hortonolite-dunite of the Onverwacht Mine, were very kindly determined for the writer by Professor L. Duparc and M. Marcel Gysin of the Mineralogical Laboratory, University of Geneva. They report as follows:—

"The amphibole is anhedral being slightly elongated parallel to (110). The prismatic cleavage is well developed, the angle between the cleavage planes, as determined on the Féderoff stage, is 124° . In the amphibole, which in ordinary light appears dark brown, one sees occasional small orientated inclusions of a green amphibole.

"The Brown Amphibole."

"The plane of the optic axes is parallel to (010). The acute bisectrix is negative = Z.

"The optic angle for sodium light, measured on the Féderoff stage, is 78° ; measured directly by the Wülfing apparatus = $77^\circ 16'$.

"The extinction angle $c : X = 12^\circ$, the same value being obtained using the Féderoff stage and by direct measurement in sections cut parallel to (010).

"The maximum birefringence $\gamma - \alpha = 0.019$.

"The pleochroism is as follows: Z = dark brown; Y = brown; X = very pale brown to yellow.

"The refractive indices could not be accurately measured by the immersion method owing to the deep colour of the mineral.

"The Green Amphibole."

"Crystal form, cleavage and optical orientation are the same as for the brown amphibole.

"According to measurements on the Féderoff stage the optic angle is greater than that of the brown variety, it is even possible that the acute bisectrix is here positive, but owing to the very small size of the inclusions this could not be definitely determined.

"The extinction angle on (010) is 19° . The pleochroism is as follows:— Z = pale green; Y = greenish; X = very light brown to yellow."

Professor Duparc remarks that the brown amphibole is very similar to the variety which he has named¹ sorétite. This occurs in issite dykes cutting the Uralian dunite massifs.

In the Mooihoek hornblende the pleochroism is different. Here Y = reddish brown.

The black hornblende is sometimes in parallel intergrowth with diallage. The dark and light coloured varieties of hornblende are also, as previously stated, found intergrown and rimming one another. The diallage is almost colourless in thin sections, but in thick sections it is faintly pleochroic in shades of very pale brownish-red and brownish-pink. It has an extinction angle $c : X$ of 42° .

The phlogopite is uniaxial. In the upper levels of the mines it is, as a rule, considerably chloritised and seamed with secondary magnesite.

One such specimen of altered phlogopite from the 150-foot level of the Onverwacht Mine was found by analysis in the Government Chemical Laboratory, Johannesburg, to contain

¹ *Bull. de Soc. Franç de Mineralogie*, 1903, p. 126.

0.38 per cent. of fluorine. In its original unaltered condition it would probably be much richer in that constituent. To the significance of the presence of such fluorine-bearing phlogopite in the ore body further reference will be made.

The ilmenite and magnetite are definitely interstitial to the hortonolite and evidently crystallised after it. Sulphides, when present, are also interstitial to the silicates.

Chromite.—Three distinct types of chromite are present. The first occurs in well-formed cubical crystals completely enclosed in hortonolite. It appears to be quite normal in its chemical and physical properties.

Another variety (?) of chromite occurring in the Onverwacht Mine and described by R. A. Cooper (42) is strongly magnetic, and appears to be abnormally rich in iron. An analysis by R. A. Cooper showed:—

	Per cent.
Cr ₂ O ₃	43.00
FeO + Fe ₂ O ₃	52.00
MgO	5.00

It is probable that we have to do here with an isomorphous mixture of chromite and magnetite.

A third variety, greatly in evidence in the Onverwacht "Pipe" on and in the neighbourhood of the 250-foot level, occurs in irregular patches and tabular bodies of considerable size. It has, as will be shown, been derived from the fragmentation of a seam of chromite intersected by the dunite "pipe."

Sulphides are present below water-level in small specks which are interstitial to the silicates. Pyrrhotite, chalcopyrite, and chalmersite have been identified, and pentlandite is probably also present.

There are obtained from the crushing of oxidised ore of the Onverwacht "Pipe" small grains and scales of native copper. It is not clear whether the copper is a primary constituent of the dunite or of supergene origin. Films of supergene chalcocite were noted by the writer near water-level in the Onverwacht Mine.

The order of crystallisation of the minerals present appears to differ in different specimens. Normally it is chromite, hortonolite, diopside, hornblende, ilmenite. Locally, however, it is chromite, hornblende, hortonolite, diopside, and ilmenite.

Thin sections cut across the contact between the hortonolite-

dunite and the olivine-dunite in the Onverwacht "Pipe" show that the contact is a very irregular one, and that the hortonolite is clearly moulded on the olivine, proving that it crystallised later.

Platinum.—Platinum, as already stated, occurs in the dunite mainly in the metallic state, partly as iron-rich *a* polyxene, and partly as sperrylite and the platinum sulph-arsenide, already referred to.

The metallic platinum is found in well-formed crystals and crystal aggregates, and also in irregular nuggety and spike-shaped forms up to 0.8 cm. across.

Numerous specimens showing visible platinum have been found. Some of them show crystals of platinum completely enclosed in big grains of hortonolite, proving that part at least of the metal crystallised before the iron-rich olivine. Some of the big nuggets and irregular grains are, however, definitely interstitial to the hortonolite and other silicates, so that the crystallisation of the platinum probably overlapped that of these minerals.

Platinum is also often found intergrown with chromite. When this is the case it is always moulded on that mineral, and definitely later. On the other hand it clearly crystallised before magnetite and magnetiferous ilmenite in both of which it is sometimes found completely embedded.

The crystallisation of the platinum thus appears to have taken place over a considerable range of temperature. It evidently began to separate after the chromite, but before the silicates, and its separation must have continued after that of the silicates. It was, however, apparently completed before the magnetite and ilmenite began to crystallise.

It has been suggested elsewhere that two distinct generations of platinum are present since it occurs in both well-formed crystals and irregular grains.

The writer has, however, seen irregularly elongated spike-like grains showing crystal faces at one end and irregular rounded terminations at the other.

Of the precise manner of occurrence of the sperrylite and the platinum sulph-arsenide, and their relations to the associated minerals nothing definite is known, since, so far as the writer is aware, they have not been observed *in situ*.

Further particulars in regard to the distribution of the platinum will be given in describing the individual dunite occurrences.

Chemical Composition.—Two fairly complete analyses of the hortonolite-dunite have been made. One is of an outcrop specimen from Onverwacht, which assayed 33.8 dwts. of platinum per short ton. The other is of a large sample of unweathered ore from the workings of the Mooihoek Mine.

There is also available an analysis of the remarkable hortonolite-ilmenitite forming segregations in the dunite of this mine.

The several analyses, together with the partial analyses¹ of three samples of the Onverwacht dunite, taken by the writer, are given in the subjoined table:—

	I.	II.	III.	IV.	V.	VI.	VII.
SiO ₂ . . .	34.25	34.38	36.72	22.30	34.00	33.90	34.70
TiO ₂ . . .	0.05	0.05	trace	14.40	nil	0.80	nil
Al ₂ O ₃ . . .	1.45	1.46	1.63	0.40	...	...	...
Cr ₂ O ₃ . . .	0.10	0.10	nil	trace	0.10	0.20	0.10
Fe ₂ O ₃ . . .	2.90	0.03	n.d.	5.30	n.d.	n.d.	n.d.
FeO . . .	35.55	38.30	38.04	40.60	37.80	39.00	37.90
NiO . . .	trace	trace	trace	trace	n.d.	...	n.d.
MnO . . .	0.40	0.40	1.05	0.55	n.d.	...	n.d.
MgO . . .	22.00	22.09	22.18	14.20	23.60	21.00	21.10
CaO . . .	2.35	2.36	0.50	0.90	nil	0.10	0.50
K ₂ O . . .	nil	nil	trace	0.15 {	n.d.	...	...
Na ₂ O . . .	0.20	0.20	0.32		n.d.	...	...
P ₂ O ₅ . . .	0.05	0.05	trace		n.d.	...	...
CO ₂ . . .	trace	trace	trace	trace	n.d.	...	...
S . . .	n.d.	n.d.	0.05	0.35	...	...	...
H ₂ O . . .	0.55	0.55	...	1.20	n.d.	...	...
Total . . .	99.85	100.00	100.49	100.35 ¹	...	...	...
Platinum . . .	0.0057 (33.8 dwts. per ton)	...	n.d.	0.0014 (8.4 dwts. per ton)	0.0012 (7 dwts. per ton)	trace	nil
Specific gravity	3.752	...	3.83	...	...	...	...

¹ Less oxygen equivalent of sulphur = 0.20 per cent.

- I. Hortonolite-dunite from outcrop, Onverwacht Platinum Mine, Lydenburg District, Transvaal. Anal., H. G. Weall; Assayer, F. W. Watson.
- II. Analysis I. recalculated to 100 per cent. on the assumption made below.
- III. Hortonolite-dunite, Mooihoek Platinum Mine, Lydenburg District. Anal., A. McA. Johnston, Goldfields Laboratory.
- IV. Hortonolite-ilmenitite, 200-foot level, Driekop Mine. Anal., H. G. Weall.
- V. Honey-brown, coarse-grained hortonolite-dunite, 200-foot level, Onverwacht Mine. Anal., R. A. Cooper.
- VI. Greenish hortonolite-dunite, 500-foot level, Onverwacht Mine. Anal., R. A. Cooper.
- VII. Dark-green hortonolite-dunite from depth of 596 feet, Onverwacht Mine Anal., R. A. Cooper.

¹ These analyses are published by courtesy of Dr E. T. Mellor.

In regard to No. I. it should be stated that, as the particular specimen analysed contained only 0.05 per cent. of magnetite, the ferric oxide shown by the analysis is to be attributed almost entirely to the incipient oxidation of the hortonolite, already referred to. The analysis has accordingly been recalculated on the assumption that all of the ferric oxide except that required to form 0.05 per cent. of magnetite, was originally present as ferrous oxide. The results are given in column II.

It will be noted that the Mooihoek hortonolite-dunite is very similar in composition to the Onverwacht rock, but that it is somewhat richer in manganous oxide and poorer in lime.

It will also be noted that there is no appreciable difference in composition between the Onverwacht dunite rich in platinum (Anal. II.), that fairly poor in platinum (Anal. V.) and that barren of platinum (Anals. VI. and VII.).

The norms calculated from Analyses II. and IV. are as follows:—

	II.	IV.
Nepheline	0.85	0.56
Anorthite	3.34	0.56
Hortonolite	89.15	60.82
Akermanite	3.03	1.89
Ilmenite	...	27.36
Magnetite	0.05	7.66
Chromite	0.23	trace
Pyrrhotite	nil	0.88
FeO + MgO (unaccounted for) .	2.69	...
H ₂ O	0.55	...
Total	<u>99.89</u>	<u>99.73</u>

The symbol of the Onverwacht hortonolite-dunite is

V.1.5.1.3.

The writer has elsewhere proposed the normative *onverwachtose* for this subrang, into which the analysis of the Mooihoek dunite also falls.

The symbol of the hortonolite-ilmenitite from Mooihoek is

V.2.5.1.3.

The normative name *mooihoekose* is proposed for it.

Petrography of the Olivine-Dunite.—The olivine-dunite, with which are associated the occurrences of hortonolite-dunite and iron-rich olivine-dunite of the Lydenburg district, is a medium-grained, dark-green, brown-weathering rock. It everywhere

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shows more or less advanced serpentinisation and, at Mooihoek, has been completely converted into serpentine and silicified serpentine at and near the surface.

Thin sections of the better preserved dunite show it to have a hypidiomorphic granular texture and to consist predominantly of grains and crystals of olivine averaging 0.85 mm. in diameter.

	I.	II.	III.	IV.
SiO ₂ . . .	36.55	38.4	35.9	40.03
TiO ₂ . . .	0.10	nil	...	nil
Cr ₂ O ₃ . . .	0.40	0.5	...	0.50
Al ₂ O ₃ . . .	1.70	} 5.9 {	...	0.57
Fe ₂ O ₃ . . .	1.80		7.85	nil
FeO . . .	16.85		12.5	8.29
NiO . . .	trace	n.d.	...	0.29
MnO . . .	0.15	n.d.	...	0.06
MgO . . .	37.95	38.0	35.8	48.8
CaO . . .	1.00	nil	...	nil
K ₂ O, Na ₂ O . .	trace	...	...	...
P ₂ O ₅ . . .	trace	...	...	...
S . . .	0.40	...	...	...
H ₂ O+ . . .	2.60	n.d.	2.70	1.28 ¹
H ₂ O- . . .	0.40	n.d.	1.05	...
CO ₂ . . .	0.25	...	...	...
Total . . .	100.15	99.3	95.80	99.82
Less O equivalent of S . . .	0.20			
Total . . .	99.95			

¹ Ignition.

- I. Olivine-dunite, 200-foot level, Mooihoek Platinum Mine, Lydenburg District. Anal., H. G. Weall.
- II. Brown-weathered olivine-dunite in contact with hortonolite-dunite, 65-foot level, Onverwacht Mine, Lydenburg District. Anal., R. A. Cooper.
- III. Weathered olivine-dunite from outcrop, Onverwacht Mine, Lydenburg District. Anal., H. G. Weall.
- IV. Fresh olivine-dunite, Nijnie Tagilski, Ural Mountains. Quoted from Zavaritski, A., *Primary Platinum Deposits of the Urals*, p. 7.

The olivine is accompanied by subordinate amounts of chromite, magnetite, diallage, and magmatic sulphides. The chromite occurs partly in well-formed crystals enclosed in the olivine and partly as irregular interstitial grains moulded on that mineral, its crystallisation having evidently followed that of the olivine. Locally the crystals and grains of the mineral are segregated in irregular schlieren and patches. Diallage is always present, and is sometimes sufficiently abundant to bring the rock within the definition of olivine-wehrlite. It occurs in

irregular grains up to 1.4 cm. across, which are moulded on and enclose grains of olivine. It was thus clearly of later crystallisation than that mineral. Where big grains of diallage are present the texture of the rock becomes pseudoporphyratic poikilitic. Among the sulphide specks which are interstitial to the silicates and chromite, pyrrhotite and chalmersite have been provisionally identified.

The chemical analysis of a fairly well-preserved specimen of the dunite from the 200-foot level of the Mooihoek Platinum Mine is given in column I. of the table on page 62. Column II. contains the partial analysis of a specimen taken at the contact with the hortonolite-dunite "pipe" on the 65-foot level of the Onverwacht Mine, and column III. a partial analysis of another specimen of serpentinised dunite from the outcrop of the Onverwacht Mine.

For comparison there is adduced in column IV. an analysis of a specimen of absolutely fresh platinum-bearing olivine-dunite from a depth of 2000 feet in a borehole put down in the Nijne Tagilski region. It will be noted that the Uralian rock is much richer in magnesia and much poorer in ferrous oxide than the Lydenburg dunites.

The norm calculated from the analysis of the Mooihoek dunite, column I., is as follows:—

	Per cent.
Anorthite	4.17
Corundum	0.20
Olivine	87.74
Chromite	0.67
Ilmenite	0.15
Magnetite	2.55
Pyrrhotite	1.00
Dolomite	0.52
H ₂ O	2.60
Total	<u>99.60</u>

The symbol, according to the C.I.P.W. classification, is
V.1.5.1.2.

The Individual Occurrences.

Type I. A. Deposits of Hortonolite-Dunite in Olivine-Dunite—Onverwacht, No. 330.—The amazing ore body that forms the basis of the Onverwacht Mine has now ¹ been

¹ November 1928.

admirably exposed by means of shafts, tunnels, and stopes to a vertical depth of nearly 800 feet and, a practically barren zone of some 250 feet having been passed through, is still carrying platinum values at that depth.

While much remains to be learned about the ore-body, existing exposures prove that it is an irregular parsnip-shaped segregation of hortonolite-dunite and hortonolite-wehrilite within a much larger body of olivine-dunite that exhibits a transgressive or discordant relation toward the rocks surrounding it.

Nothing definite is known in regard to the shape or extent of the body of olivine-dunite, but in the direction of the section (Fig. 3) it has the character of a steeply-inclined pipe.

The hortonolite-dunite body is inclined at an average angle of $78^{\circ} 30'$ in a direction S. 28° E., or, in other words, roughly at right angles to the general pseudostratification of the rocks of this part of the Norite Zone. As these rocks were probably originally horizontal, the hortonolite-dunite "pipe" itself was thus evidently, when formed, vertical or approximately vertical in posture.

The original outcrop of the hortonolite-dunite, of which no trace now remains, gave rise to a small knoll or platform on the western slopes of a long, low, bush-clad ridge that rises from 250 feet to 350 feet above the level of the valleys on either side.

The ridge is built of bronzitite forming part of a huge sheet of that rock, dipping to the west at about 13 degrees. It encloses at least two seams of chromitite which, in conformity with the bronzitite and the general pseudostratification, dip to the west at the same angle as that rock. The more important seam, to which further reference will be made later, outcrops on the eastern slopes of the ridge.

The bronzitite is a medium to rather coarse-grained rock composed essentially of interlocking prismatic and irregular individuals of bronzite. It is distinctly pseudostratified. The rock, throughout the thickness of the great sheet, is very uniform in appearance, that from the bottom of the vertical shaft at a depth of 750 feet being identical, apart from its better state of preservation, with that exposed at the surface. Bronzitite of this type has been described in detail elsewhere.¹

The olivine-dunite enclosing the hortonolite-dunite "pipe"

¹ Cf. Wagner, P. A., *Memoir No. 21, Geol. Sur. Union of S. Africa.*

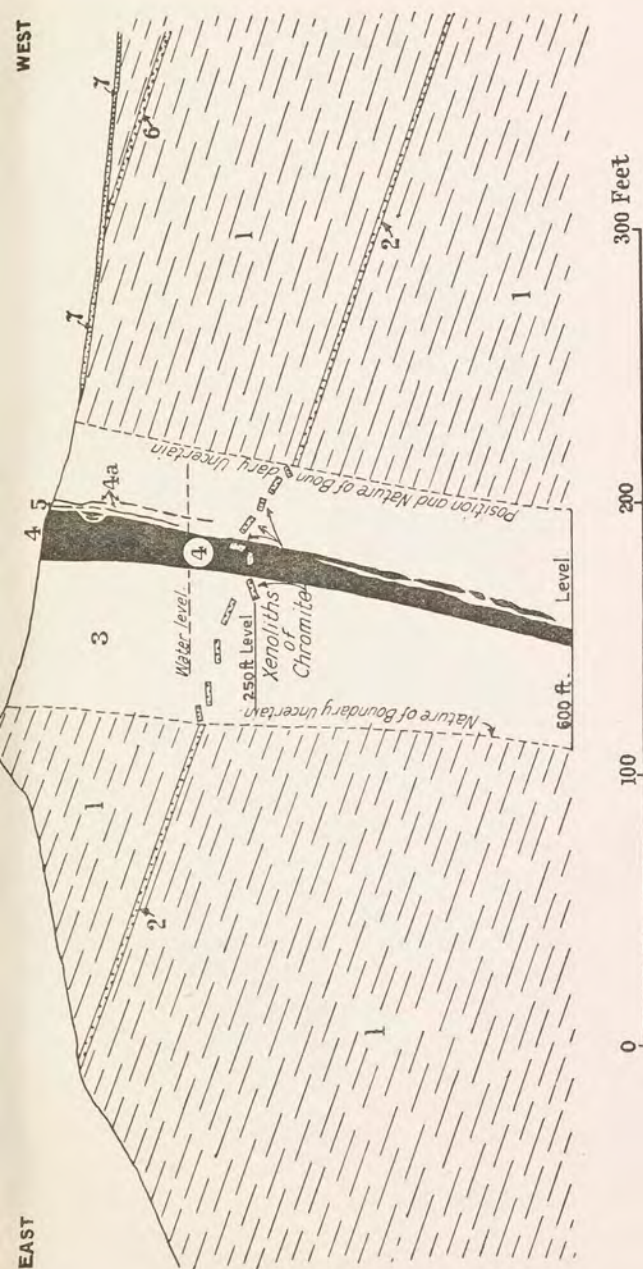


FIG. 3.—Diagrammatic Geological Section across the Onverwacht Platinum "Pipe."

1. Bronzite with finely disseminated Chromite.
2. Lower Chromite.
3. Olivine Dunite and Wehrlite.
4. Main body of Hortonolite-Dunite.
- 4a. Veins of Hortonolite-Dunite.
5. Vein of Diallage-hornblende-hortonolite rock, merging locally into Hortonolite-Dunite.
6. Upper Chromite.
7. Platinum-bearing Rubble and Eluvium.

presents no features of special interest. At and near the surface it exhibits fairly advanced serpentinisation, and is traversed by veins and seams of dense magnesite. These occupy three sets of joints intersecting one another approximately at right-angles; two vertical, or nearly so, and striking roughly east and west and north and south; the third horizontal. The dunite exposed on the walls of the open mine is thus seen to be traversed by a roughly rectangular network of magnesite veins, up to 9 inches in thickness, which present a striking contrast to the surrounding dark rock (Plate VIII.2). The veins and seams of magnesite become thinner at depth and disappear altogether below the 300-ft. level.

The main body of hortonolite-dunite was roughly circular in plan at the outcrop, and measured roughly 60 by 60 feet, the portion occupied by coarse-grained hortonolite-dunite being 50 by 50 feet. The hortonolite-dunite was regularly jointed and, in consequence, weathered in big rectangular slabs.

Horizontal and steeply-inclined vuggy seams and veins of quartz, chalcedony, and opal, up to 4 inches thick, or of a dense compact dull-white mixture of magnesite and opal occupying joints in the dunite, were much in evidence between the surface and the 50-ft. level. Some of them extended to a depth of 100 feet, but below that depth there was no sign of them.

The contact between the hortonolite-dunite and olivine-dunite, while well-defined, was extremely irregular, the main body of the first-named rock sending out wedge-shaped, carrot-shaped, and irregular ore-shoots into the surrounding olivine-dunite. This feature was also observed in all the underground levels. On the 65-ft. level, while the northern, eastern, and southern limits were clearly defined, the western part of the hortonolite-dunite body was much seamed and interspersed with patches and big bodies of olivine-dunite, rendering it difficult to draw a boundary between the two rocks.

As a result of this encroachment of the olivine-dunite on the main hortonolite-dunite "pipe," the area of the "pipe" on this level was considerably smaller than on the surface.

It should be stated that the accompanying plan (Fig. 4) of the 65-ft. level shows the limits of the area carrying workable amounts of platinum and not those of the hortonolite-dunite itself. This occupied a smaller area on the western side.

PLATE VIII



1. Portion of the original outcrop of hortonolite-dunite on Onverwacht, No. 330.



2. Section exposed on southern wall of open mine on Onverwacht, No. 330. Shows serpentinised olivine-dunite traversed by veins of dense magnesite.



On the 100-ft. level the area of the "pipe" was bigger and measured 2925 square feet, being here regularly oval in transverse section. Below this it decreased steadily, the "pipe" area at 250 feet being 2270 square feet. Below the 350-ft. level the main body was found to split up into three smaller branches or, more correctly, roots. The biggest of these persists below this level as a continuous body to the greatest depth so far attained, and still has an area of approximately 420 square feet on the 750-ft. level.

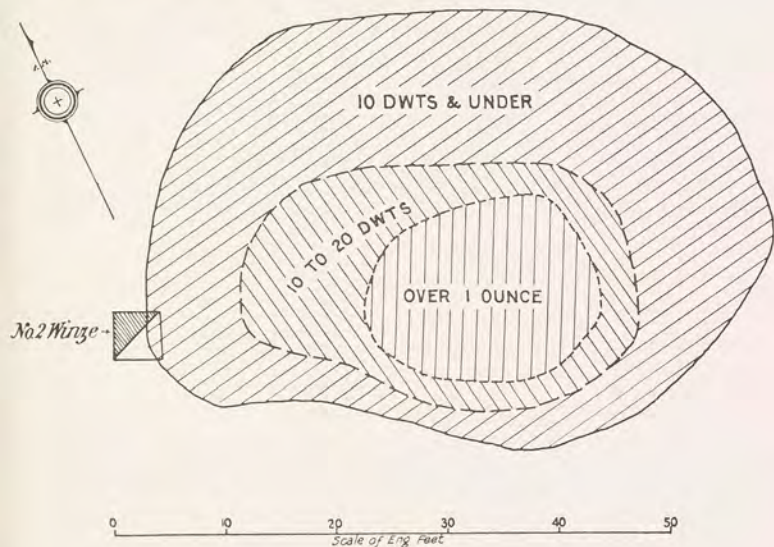


FIG. 4.—Assay Plan of the 65-ft. Level, Onverwacht Mine, showing average platinum values.

The other roots are replaced below the 450-ft. level by irregular patches and seams of hortonolite-dunite roughly paralleling the main root.

On the 550-ft. level there are three definite bodies of hortonolite-dunite enclosed in coarse hortonolite-wehrnite. The main body measures 25 by 25 ft. The hortonolite-dunite of all three bodies, whether platinum-bearing or barren, is identical in appearance and chemical composition with the hortonolite-dunite exposed in the upper levels of the mine.

The central part of the ore body, as already indicated, is

occupied by massive coarse-grained hortonolite-dunite, often showing hortonolite individuals up to 2 inches across.

Big black anhedrons of hornblende are in places much in evidence, and the dunite is interspersed with irregular patches and schlieren, up to 8 inches across, composed of criss-crossing plates and books of greenish-bronze coloured phlogopite.

Such patches were much in evidence on the 100-ft. level to the north and south of the "No. 1" Winze. It is worth recording that one of them occurs in close proximity to the point where the sample was taken that gave the highest assay value, namely, 137.8 dwts. per short ton, recorded from the upper levels of the mine.

On the 200-ft. level patches of magnetiferous ilmenite were much in evidence, and on the 250-ft. level and some distance above and below it the hortonolite-dunite was full of big xenoliths and slabs of chromitite. It should be stated in explanation that the composite olivine-dunite—hortonolite-dunite "pipe" intersects the chromite seam exposed on the eastern slopes of the Onverwacht ridge at a depth of about 250 feet in the main workings. The seam has been broken up by the dunite, and big tabular masses of the chromitite, dipping in all directions, are found scattered through both the olivine-dunite and the hortonolite-dunite (*cf.* Fig. 3).

From the economic point of view these big chromitite xenoliths were of great importance, since they apparently acted like sponges so far as platinum was concerned.

The highest values anywhere struck were in the chromitite xenoliths and in their neighbourhood. These often showed coarse visible platinum which is never seen in the normal chromitite, even when platinum-bearing. Further reference is made below to this interesting phenomenon.

Distribution of the Platinum.—The platinum content of the hortonolite-dunite ranges from nil to 1213 dwts. per short ton (0.205 per cent.).

At the surface in the upper levels of the mine the central part of the "pipe" was everywhere found to be very rich in platinum, the platinum content of the hortonolite-dunite decreasing uniformly towards its margin.

In the upper levels the central part of the "pipe" averaged well over 1 oz. of platinum to the ton (Fig. 4).

The richest ore actually encountered was in the winze

PLATE IX



1. The Onverwacht Mine as it appears at present.



2. Treatment Plant of the Onverwacht Platinum Mine.



between the 200-ft. and 250-ft. levels. One sample taken at 229 feet along the contact of a xenolith of chromitite with the hortonolite-dunite returned the assay value given above, and one at 230 feet gave 1095 dwts. The best average values were encountered on the 250-ft. level, which showed an average of 18.4 dwts. over a pay-area of 2270 square feet.

In the upper levels of the mine the best value was 134 dwts., obtained on the 150-ft. level near a segregation of phlogopite.

Below the 250-ft. level there was a steady falling off in values, and between 550 feet and 700 feet the "pipe" was practically barren. At 700 feet good values were again struck, the pay area averaging 11 dwts. over 420 square feet. These good values persist to the 750-ft. level which averages 9.5 dwts. over a pay-area of 420 square feet. On the 800-ft. level much lower values were again encountered.

To what depth the platinum will persist is a matter for conjecture, but, looking at it from a strictly geological point of view, there is no reason why it should not go down to as great a depth as the surrounding olivine-dunite, and this, while it is apparently beginning to shrink in area on the 750-ft. level, is still a very big body of rock at that depth.

There is, as already stated, no difference chemically or mineralogically between the platinum-rich, platinum-poor and platinum-barren hortonolite-dunite. That from the lower levels is slightly different in colour but otherwise identical. As there is thus no difference chemically or mineralogically between the platinum-bearing and non-platinum-bearing hortonolite-dunite, the cause of the localisation of the platinum values must be environmental. We may, therefore, next inquire: what were the environmental facts involved? Three suggest themselves, namely:—

- (1) Temperature.
- (2) Pressure.
- (3) The chromite seam cut by the "pipe" at a depth of 250 feet.

The writer was originally inclined to think that all three facts had contributed.

It is quite easy to see, for instance, that if, as there is reason to believe, the platinum was originally present as a gaseous compound, temperature and pressure at the time of

the formation of the ore body might very well have controlled not only the depth to which the platinum values will persist but also the horizon at which the best ore occurs. In view, however, of the recurrence of good values at 700 feet and below this level, in dunite identical with the barren dunite exposed on the levels above, it is difficult to see how purely physical conditions could have been responsible.

The chromite seam struck on the 250-ft. level was without doubt responsible for the remarkable concentration of the platinum on that level. As stated above, the richest ore was struck on it, and the abrupt falling off of values both above and below the level indicate, as previously stated, that the chromite acted like a great sponge, collecting the metal within itself and in the dunite immediately adjacent to it.

Whether the action was purely physical or chemical it is impossible to say. Platinum was probably distilled from the magma into the pores of the xenoliths, as, on any other assumption, the interchange of material from the magma into the interior of the xenoliths would be difficult to explain. On this view the chromite merely fixed certain exhalations from the magma. Assuming that it did, and that the ore body cooled from the top downward, it is easy to see that the chromite or chromite-rich dunite might have continued to abstract platinum from the still liquid dunite below the 250-ft. level after the upper part had consolidated. This would account for the marked impoverishment for perhaps 100 feet below the 250-ft. level, but hardly for that at greater depths.

Thus at the present time no adequate explanation for the irregular distribution of the platinum in the hortonolite-dunite is forthcoming.

Veins Paralleling the Main Ore Body.—As will be seen from the section (Fig. 3 on p. 65), the main ore body is paralleled on the west by thin veins of coarse-grained hortonolite-dunite and pegmatitic diallage-hornblende-phlogopite-hortonolite rock. Similar veins and segregations are met with in other parts of the olivine-dunite body away from the plane of section. In one struck in an incline, northwest of the main "pipe," hortonolite is accompanied by lustrous magnetiferous ilmenite. These isolated veins and segregations, without exception, contain notable amounts of platinum, while the olivine-dunite carries at the best a fraction of a pennyweight per ton.

The veins, as already indicated, are composed either of hortonolite alone or of hortonolite accompanied by diallage, hornblende, and phlogopite. They range in thickness from 6 inches to 2 feet. One of the hortonolite-dunite veins is seen, on the south side of the ladder-way down to "No. 2" Winze, to terminate abruptly upward with a blunt rounded end. The veins carry platinum, and assays up to 13 dwts. per ton have been recorded from them.

Special interest attaches to the vein of pegmatitic diallage-hornblende-phlogopite-hortonolite rock, which is identical with those found paralleling the Mooihoek "pipe," as it furnishes a connecting link between the two main types of hortonolite-dunite occurrence. It varies in thickness from 6 inches to 8 inches and is well exposed to the 50-ft. level. Like most pegmatite veins, it is extraordinarily variable in character. Near the surface it consists of a coarse-grained aggregate of the minerals named, the order of abundance being that stated. Between the surface and the ladder-platform at a depth of 25 feet it was found at two points to consist almost entirely of phlogopite, while just above the 50-ft. level the complete width of the vein is occupied by coarsely crystalline hortonolite-dunite.

Rubble Ore.—The slopes below the original knoll formed of the olivine-dunite are covered with rubble and fine wash derived from the disintegration of that rock.

This detrital ore everywhere pans well, and all of it will be put through the treatment plant.

An analysis of this rubble ore from the slopes near the knoll gave the following result:—

	Per cent.
SiO ₂	34.5
Cr ₂ O ₃	5.6
FeO	39.5
MgO	14.9
Combined Water	4.4

It will be noted that, apart from containing a good deal of residual chromite, the rubble is very similar in composition to the hortonolite-dunite occurring in place.

Mooihoek, No. 147.—The occurrence on Mooihoek, No. 147, where Dr Merensky made his original discovery of platinum in the mother rock, is situated in the south-western corner of the farm.

The dunite again gives rise to a low boulder-strewn knoll (Plate X.1) on the western slopes of a low ridge. The crest and upper part of the ridge are built of rather fine-grained spotted anorthositic norite, and much the same type of anorthositic norite is exposed to the west and south of the mine workings. It forms a great sheet conforming to the general pseudostratification of the Norite Zone, the dip being to the west-south-west at about 12 degrees.

The norite sheet is underlain by an even thicker sheet of bronzitite and feldspathic bronzitite in which are seams of the lower chromite horizon.

The anorthositic norite probably stands in complementary relation to the pyroxenite, as has been suggested for the similar occurrences of these rocks in the Rustenburg district.¹

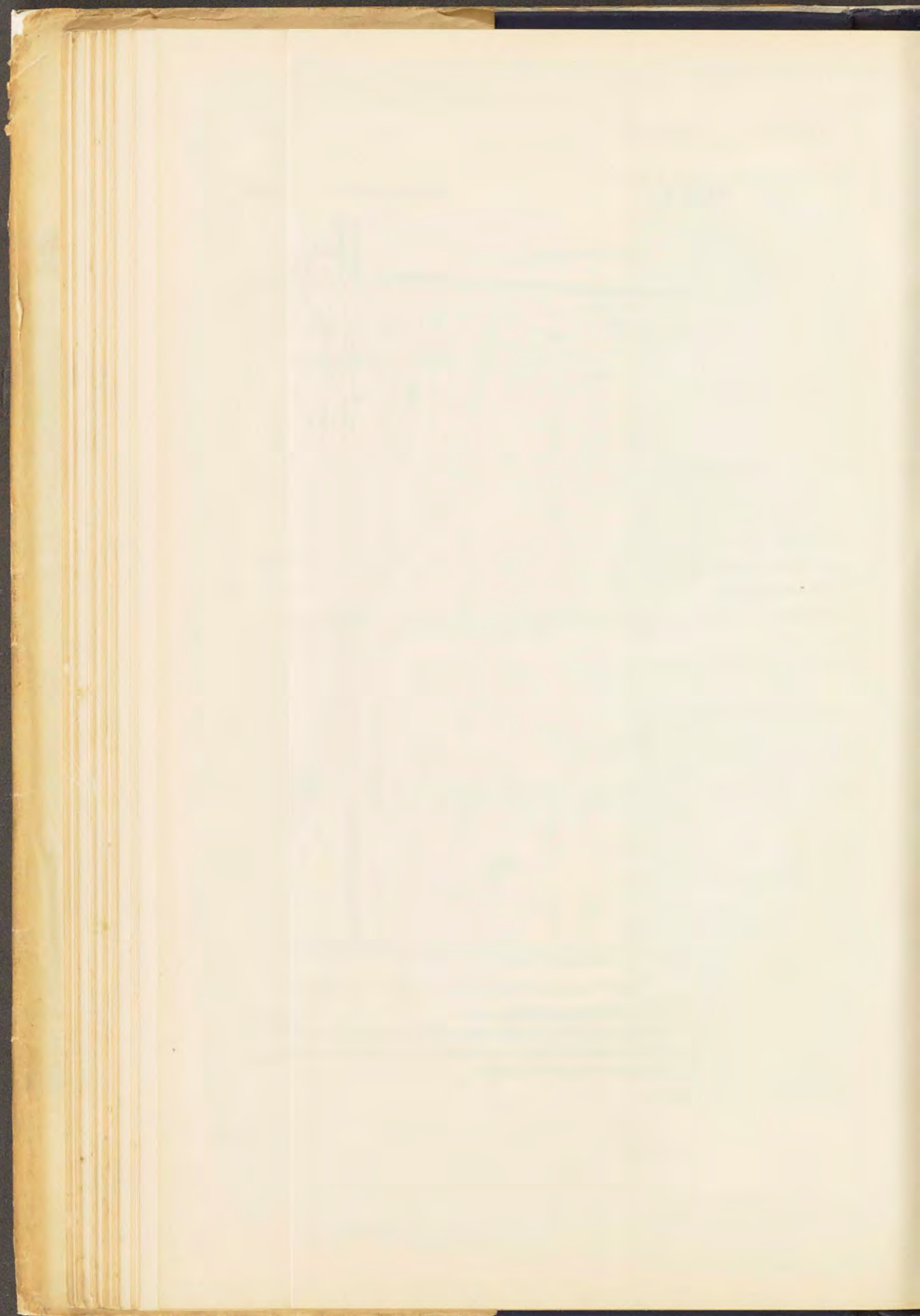
The main hortonolite-dunite body is surrounded on all sides by outcrops and float of rusty weathering silicified serpentine which, as will be shown, has been derived from the atmospheric weathering of olivine-dunite enclosing the hortonolite-dunite and apparently forming a big "pipe" of roughly circular outline.

The serpentine and olivine-dunite immediately surrounding the main body of hortonolite-dunite are cut by numerous vertical or steeply-inclined veins of coarse pegmatitic hortonolite-dunite, hortonolite-wehrlite, diallagite and diallage, phlogopite, hornblende and magnetite rock. The veins belong to two systems, one striking 10 degrees north of west and the other almost at right angles to this direction. They will be dealt with later.

The olivine-dunite "pipe" appears itself to be encased in a continuous outer shell of coarse pegmatitic diallagite and feldspathic pyroxenite, which pass locally into coarse pegmatitic olivine gabbro. It is of interest to record that on the 350-ft. level of the mine boulder-like inclusions of the anorthositic norite were found in these rocks and in the olivine-dunite.

The relation between the pegmatitic diallagite and allied rocks and the olivine-dunite, and between the olivine- and hortonolite-dunite, can be well studied in the tunnels driven on the 250-ft. and 350-ft. levels to intersect the main hortonolite body, from the vertical shaft situated some 300 feet S. 35° W. of it.

¹ Cf. Wagner, P.A. (26), p. 59.



The pegmatitic diallagite is a handsome rock composed essentially of big prismatic anhedral crystals of diallage, up to 15 cm. across, which reflect the light from lustrous cleavage surfaces. The diallage is sometimes in parallel intergrowth with strongly pleochroic brown hornblende, and subordinate amounts of plagioclase and phlogopite are in places present. In places the diallagite encloses small patches of hortonolite.

The olivine-gabbro exposed in the main vertical shaft and in the 350-ft. cross-cut is a coarse-grained rock composed, in order of abundance, of serpentinised olivine, plagioclase, and diallage. The texture is poikilitic, both the plagioclase and the diallage holding rounded chadocrysts of serpentinised olivine. The gabbro appears on the 350-ft. level to merge imperceptibly into the olivine-dunite and is clearly related genetically to that rock. On the 350-ft. level the thickness of the composite diallagite-gabbro zone is less than 10 feet. It is separated from the main body of olivine-dunite by a body of sheared serpentinised olivine-dunite.

The underground mine workings prove that the main "pay-body" of hortonolite-dunite is in the form of a pipe dipping at an angle of about 80 degrees in a direction 76 degrees east of north, or almost exactly at right-angles to the general pseudostratification of the rocks of the Norite Zone. It is, as previously stated, enclosed in a much bigger, apparently pipe-shaped body of olivine-dunite and wehrlite.

It would appear, therefore, that we have to do with a great composite "pipe" or stock composed of an outer zone of pegmatitic diallagite and olivine-gabbro, surrounding a thick annular body of olivine-dunite or serpentine derived from it, which, in turn, encases a much smaller pipe-shaped body of hortonolite-dunite. The diameter of the greater "pipe" from north to south is roughly 700 feet, while from east to west it varies from 600 to 850 feet.

The actual section revealed by the main shaft and cross-cuts is shown in Fig. 5.

Dealing first with the main body of hortonolite-dunite: this, as already stated, forms a pipe-shaped body at the very centre of a great composite "pipe" cutting almost perpendicularly across the associated rocks of the Norite Zone.

At the surface, where it measured roughly 51 by 42 feet, it bulged slightly toward the west in a lip-like projection. The

outline, while roughly circular, was very irregular in detail, with numerous small bays and protuberances.

On the sides of the main open working, which is circular in ground plan, the protuberances appear in section as dyke-like bodies radiating from the centre of the "pipe." The "pipe" roughly maintained its surface shape to a depth of 200 feet. Below this it becomes elongated in a north-north-west to south-south-east direction, the pay-area on the 350-ft. level measuring 75 by 34 feet (Fig. 6).

Near the surface and in the upper levels of the mine the "pipe" is occupied almost entirely by coarse-grained honey-brown hortonolite-dunite, interspersed with big anhedral bodies of black hornblende, books and aggregates of phlogopite up to 6 inches across, and patches of lustrous magnetiferous ilmenite. Special interest attaches in this mine to segregations of magnetiferous ilmenite and hortonolite-ilmenite, the latter being up to 3 feet across.

Below the 150-ft. level the "pipe," as defined in the accompanying diagram, no longer consists entirely of hortonolite-dunite but contains big areas of olivine-dunite. Thus, at a depth of 220 feet, the writer noted that quite a considerable portion of the pay-area consisted of olivine-dunite interspersed with patches of hortonolite-dunite, coarse-grained aggregates of hornblende, phlogopite, hortonolite and magnetiferous ilmenite. At greater depths the tendency towards the segregation of the hortonolite into smaller bodies enclosing olivine-dunite becomes even more marked. On the 350-ft. level these bodies are seen to be elongated in the direction of elongation of the main pay-area.

The platinum content of the hortonolite-dunite ranges from a fraction of a pennyweight to over 100 dwts. The values increase uniformly from the margins toward the centre of the "pipe" where they are highest. Thus, on the 350-ft. level, the average for the whole level was 6.9 dwts., whereas a winze put down at the centre of the "pipe" shows an average value of 42 dwts.

The average tenor of the ore developed throughout the mine is between 6 and 7 dwts.

High platinum values are in this mine definitely associated with phlogopite and black hornblende.

The present pay limit is about 2 dwts. and in Fig. 6, which

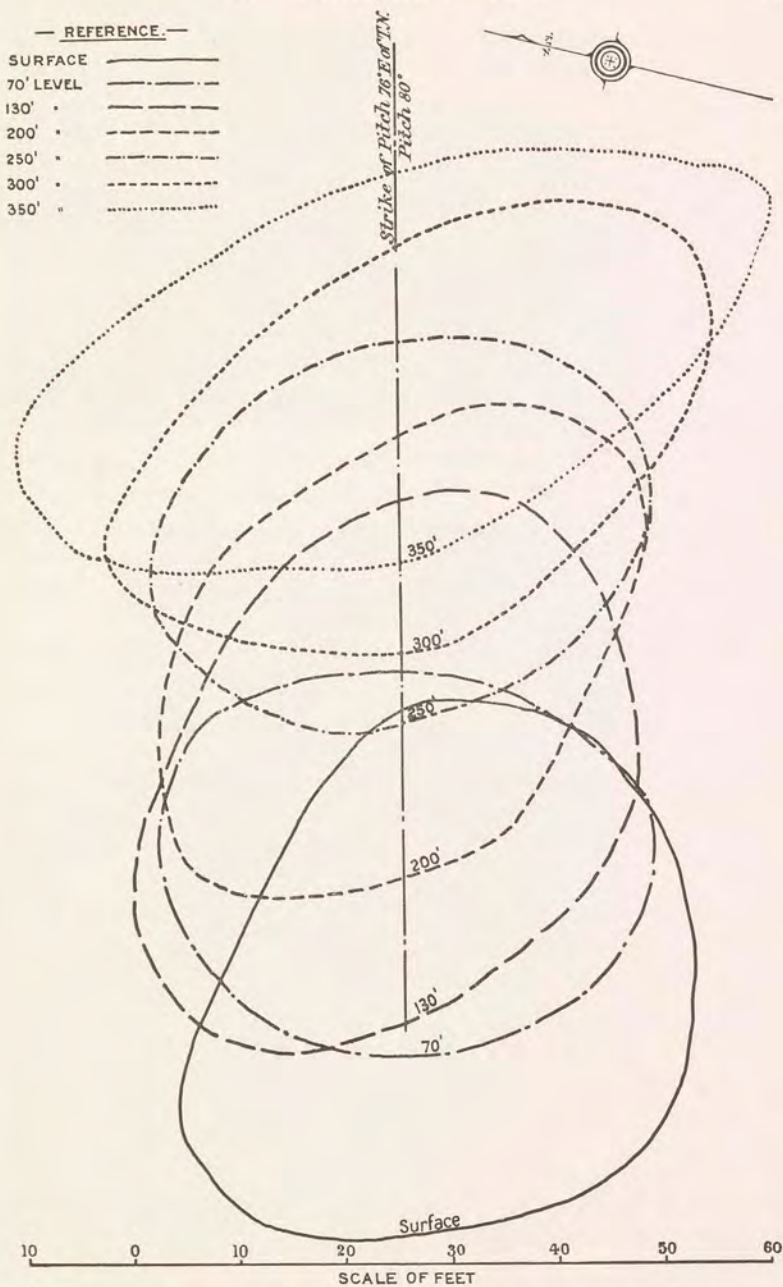


FIG. 6.—Plan showing Pay Contours of Mooihoek Hortonolite-dunite "Pipe" at different levels from the surface to 350 feet.

the writer has been allowed to publish through the courtesy of the Board of Directors of the Lydenburg Platinum Areas, Ltd., are shown the pay contours of the main Mooihoek "pipe" at different levels from the surface to 350 feet. It must be emphasised once more that the contours are not geological contours but merely delimit an area carrying workable amounts of platinum, so that, while the surface contour roughly defines the limits of the hortonolite-dunite "pipe," that on the 350-ft. level probably includes quite as much olivine-dunite as hortonolite-dunite. The olivine-dunite, it should be stated, also carries platinum and, as will be shown later, values up to 7 dwts. per ton have actually been recorded in the rock outside the limits of the "pay-pipe."

It will be noted on studying the plan that the pay-area has increased considerably at depth, which is a very gratifying feature. The platinum values on the 350-ft. level are, moreover, better than on any of the upper levels, and 30 feet of drives sampled on the 400-ft. level average 14.7 dwts. per ton.

The lowest workings are still probably quite 250 feet above the level at which they should intersect the lower chromite horizon. If our views in regard to the role played by the chromite of the lower horizon in enriching the Onverwacht "pipe" are correct, there should be a corresponding enrichment in the case of the Mooihoek occurrence, always provided, of course, that the hortonolite-dunite segregations persist to a depth at which the chromite should be intersected.

Provided that the price of platinum does not drop very considerably, the present prospects of the Mooihoek Mine must thus be voted distinctly favourable.

Pegmatitic Veins Paralleling the Main Ore Body.—These, as already stated, belong to two systems cutting one another approximately at right-angles and dipping in conformity with the main ore body. They evidently occupy two systems of shrinkage cracks in the olivine-dunite. Mining operations have proved that some of the veins persist to a considerable depth, and that at least one of them is connected with the main body of hortonolite-dunite. This particular vein is exposed on the north-west side of the 200-ft. level workings.

The veins range in thickness from an inch to 4 feet, and are sometimes seen to branch upward. In a cutting leading to the

PLATE X



1. Portion of the original knoll of hortonolite-dunite on Mooihoek, No. 147.



2. Vein of pegmatitic diallage-phlogopite-magnetite rock in serpentinised olivine-dunite, Mooihoek Platinum Mine.



main open working to the south-west, no fewer than twelve of them are exposed (Plate X.2).

The veins are pegmatitic in character and show considerable variation as regards their mineralogical composition. Some of the narrower ones consist of hortonolite-dunite or hortonolite-wehrlite, but the majority are made up of different combinations of diallage, phlogopite, lustrous black hornblende, magnetite and ilmenite which may or may not be accompanied by hortonolite. The grain throughout is very coarse. Individuals of hornblende up to 6 inches across were noted in one vein immediately east of the main ore body. This particular vein is composed, in order of abundance, of diallage, hornblende, phlogopite and magnetite.

The veins containing hortonolite carry small amounts of platinum, but most of them appear to be barren of that metal.

Their probable manner of formation will be discussed later.

Rubble Ore.—As at Onverwacht, the disintegration of the hortonolite-dunite has given rise at the surface to an accumulation of platinum-bearing rubble.

Serpentinisation of the Olivine-Dunite.—The workings of the Mooihoek Platinum Mine throw very valuable light on the problem of the origin of serpentine.

The olivine-dunite surrounding the "pipe" is, as already stated, represented on the surface by yellow, brown-weathering, silicified serpentine with veins of greenish-yellow opal. This gives place successively, when followed downward, to (a) normal serpentine, (b) almost completely serpentinised dunite, (c) partially serpentinised dunite, and (d) practically unaltered olivine-dunite.

The change from serpentine and almost completely serpentinised dunite to partially altered dunite takes place *at water-level*, namely, about 45 feet, which confirms the writer in his opinion, previously expressed,¹ that so far as the Bushveld Igneous Complex is concerned serpentinisation is a normal phenomenon under certain conditions of atmospheric weathering, and is not, as some geologists maintain, due to the action of heated water emanating from the parent dunite magma. Were magmatic waters the cause of the phenomenon, there could not possibly be the coincidence recorded above between the lower limits of the serpentine and the underground water

¹ *Trans. Geol. Soc. S. Africa*, 1925, pp. 1-17.

table; and it would also be difficult to explain why no serpentine was formed at Onverwacht where the olivine-dunite outcrops on the crest and upper slopes of a ridge at a considerable distance above the surrounding valleys.

That the change from serpentine to dunite should take place at water-level proves that the co-operation of oxygen and carbon dioxide is clearly necessary for the formation of serpentine. This is also indicated by the presence in the serpentine of veins and seams of magnesite, though these are not as abundant as at Onverwacht. It will be noted from the analysis, previously given, that the olivine-dunite exposed on the 200-ft. level of the mine still contains a good deal of serpentine. That from a depth of 400 feet is practically unaltered.

Occurrences of Hortonolite-Dunite in Pegmatitic Diallagite and Allied Rock Types.—Of this type of occurrence, where the hortonolite-dunite forms segregations in pegmatitic diallage, diallagite-ilmenite, and diallage-ilmenite-hortonolite rock, there are numerous examples in both the Rustenburg and Lydenburg districts. One from each district may briefly be referred to.

The example chosen from the Lydenburg district is a very interesting occurrence on the farm Dwarsrivier, No. 86. Here, a great intrusion having the shape of an upright wedge, and composed mainly of diallagite-pegmatite with segregations of hortonolite-dunite, cuts across the Merensky Platinum Horizon and associated rocks between Prospecting Trenches "16" and "17," the intrusion at this level being about 600 feet wide. It also cuts across the upper chromite horizon which outcrops some hundreds of feet below the Merensky Horizon. The diallagite-hortonolite-dunite intrusion does not appear to have affected in any way the platinum-bearing diallagite-norite constituting the Merensky Horizon or the chromite seam which, however, it must intersect somewhere. On the other hand, it has completely obliterated the anorthositic norite overlying and underlying the Merensky Horizon, and also certain anorthositic rocks associated with the chromite. The magma fraction from which the diallagite and hortonolite-dunite crystallised thus apparently reached the position which these rocks now occupy by a process of magmatic replacement. It is to be hoped that someone will find time to make a detailed examination of this



1. The Mooihoek Platinum Mine, showing steel head-frame in course of erection. The open mine is behind the head frame on the left, and on the right in the background is seen the ridge of anorthositic norite.



2. Central Mill at Maandagshoek, Lydenburg district, where the dunite of the Mooihoek and Driekop Mines is treated.



truly remarkable occurrence. It should be stated that the hortonolite-dunite, which occurs in vertical lenses up to several feet in thickness, carries only traces of platinum.

Rustenburg District.—There is shown in Fig. 7 the plan of a small segregation of hortonolite-dunite exposed in the bed of the Boschfontein Spruit on the farm Boschfontein, No. 489. This consists, for the most part, of coarsely crystalline hortonolite, indistinguishable in appearance from that of the original occurrence on Mooihoek in the Lydenburg district. Through the hortonolite ground are scattered big prismatic individuals of diallage, holding poikilitic inclusions of the

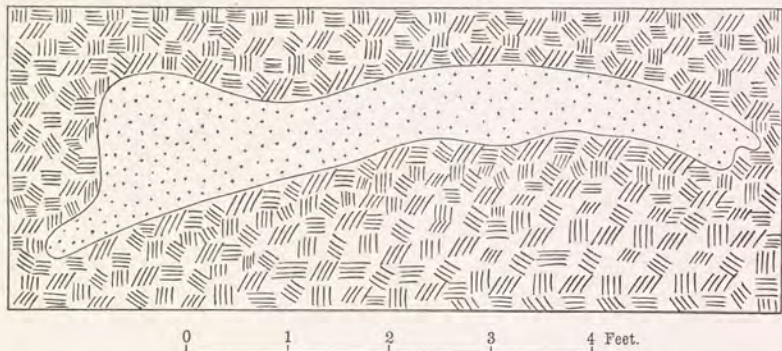


FIG. 7.—Plan of segregation of Hortonolite-dunite with isolated phenocrysts of diallage in coarse-grained Diallagite-pegmatite. Exposure in bed of Boschfontein Spruit, Boschfontein, No. 489, Rustenburg District.

former mineral. By a rapid increase in the proportion of diallage present, the dunite merges outward into coarse-grained pegmatitic diallagite composed essentially of large prisms of diallage, with which are associated subordinate amounts of ilmenite. The pegmatitic diallagite itself forms an irregular intrusion or segregation in a thick layer of pseudoporphyrific diallagite-norite overlying the upper chromite horizon of this area. The dunite was again found to contain only traces of platinum.

Type I. B. Occurrences in which Platinum is associated with Iron-Rich Olivine approaching Hyalosiderite in Composition—Driekop.—The outstanding occurrence of this type is the Driekop "pipe," situated on the farm of that name 3 miles north of Mooihoek.

This has now been successfully opened up to a depth of

460 feet and has, at the present time, the biggest ore reserve of any of the dunite deposits.

It provides us with a type of occurrence intermediate in every respect between the olivine-dunite deposits of the Uralian type and the hortonolite-dunite deposits of the Onverwacht and Mooihoek type.

Platinum occurs here in relatively small segregations, veins and schlieren of iron-rich olivine-dunite in olivine-dunite of the same type as that found on Onverwacht and Mooihoek.

As at Mooihoek, the olivine-dunite in contact with and in proximity to these segregations also carries workable amounts of platinum. The platinum, as previously indicated, occurs in the "pipe" in irregular composite bodies of iron-rich dunite and normal olivine-dunite.

The "pipe" as a whole, like the Mooihoek and Onverwacht "pipes," dips at a steep angle¹ to the east-north-east, being disposed almost at right-angles to the general pseudostratification of the rocks of the Norite Zone.

As previously stated, the platinum-bearing "pipe" forms the core of a much bigger body of olivine-dunite, which is also apparently of the nature of a pipe. This outcrops on the south-eastern slopes of a low bare-looking hill, built predominantly of bronzitite, that rises fairly abruptly from a great flat-bottomed valley lying between the Lulu Mountains and a prominent bronzitite ridge on Mooihoek, No. 147, and Driekop, No. 170.

Light-coloured spotted anorthositic norite is exposed on the lower northern and western slopes of the hill. The south-eastern slopes of the hill are covered with a platinum-bearing rubble of silicified serpentine and oxidised iron-rich dunite.

The actual platinum-bearing "pipe" is bigger than either the Mooihoek or Onverwacht "pipes," the pay-area at the surface measuring approximately 80 by 60 feet. It has been followed downward for 460 feet. The area at this depth is much the same as at the surface, and the average platinum contents appreciably higher.

The precise limits of the bigger olivine-dunite "pipe" by which it is enclosed have not as yet been defined. It appears however, like the platinum-bearing portion, to descend at a steep angle to the east-north-east.

¹ It will be noted from Fig. 8 that the dip steepens considerably below the level of the Main Adit.

PLATE XII



1. Driekop Hill at centre of photograph, with platinum workings on the left side ;
Lulu Mountains in the background.



2. Main Adit, Driekop Platinum Mine. Open Quarry above adit on the right.



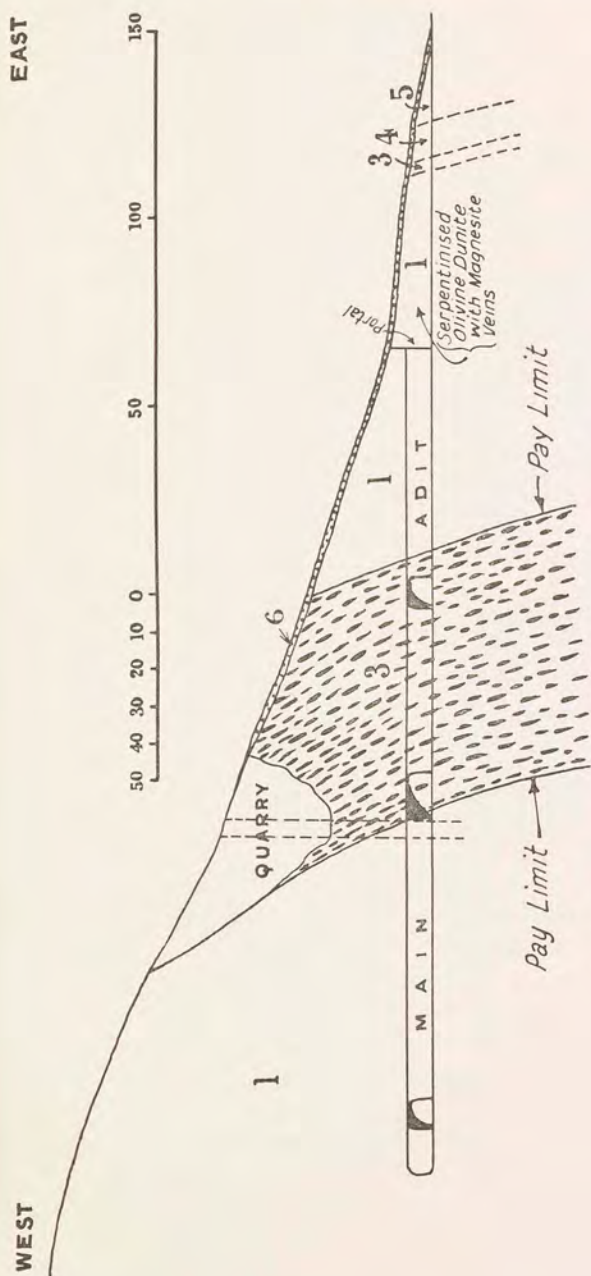


FIG. 8.—Section through upper part of Driekop Platinum Mine.

1. Olivine-dunite and Serpentine derived from it.
2. Main Platinum Pipe. Olivine-dunite with segregations of iron-rich Olivine-dunite and Wehrliite.
3. Transitional Zone between serpentinised Olivine-dunite and Medium-grained iron-rich Olivine-wehrliite and allied rocks.
4. Coarse pegmatitic diallagite with segregations of iron-rich Olivine-dunite.
5. Rubble of silicified Serpentine and oxidised iron-rich Dunite.
6. Rubble of silicified Serpentine and oxidised iron-rich Dunite.

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A fine section across a portion of the composite "pipe" is exposed in the main adit driven into the hill from the east. This shows, from east to west:—

Rubble of silicified serpentine and oxidised iron-rich dunite .	20 feet
Coarse pegmatitic diallagite with small segregations of iron-rich olivine-dunite	25 "
Medium-grained iron-rich olivine-wehrlite and olivine-diallage-magnetite rock with segregation veins of basic plagioclase	13 "
Transitional zone between iron-rich wehrlite and serpentinised olivine-dunite	3 "
Serpentinised olivine-dunite, with small boulder-like patches of bronzitite and seams and veins of magnesite passing, toward the interior of the hill, into partially serpentinised olivine-dunite	165 "
Main platinum-bearing "pipe" (olivine-dunite with veins, lenses and patches of iron-rich dunite and wehrlite) .	76 "
Barren olivine-dunite with isolated pseudo-phenocrysts of diallage	118 "

It should be stated that the iron-rich wehrlite and olivine-dunite exposed near the entrance of the adit also carry small amounts of platinum.

The main Driekop "pipe" itself, as already indicated, is a pipe-shaped body of olivine-dunite within a much bigger body of practically barren olivine-dunite, enclosing a large number of such irregular composite workable bodies of iron-rich dunite and normal olivine-dunite.

The limits of these workable bodies can only be defined by careful sampling. They change in shape and distribution from level to level, so that it is quite impossible to make any generalisation about them. Fig. 9, showing the limits of the known body of payable ore on the 160-ft. level, gives a good idea of the nature of the occurrences.

Within any particular "pay body" the platinum values range from 1.5 dwts. to 54 dwts., the higher platinum values being found in small segregations, lenses and patches of iron-rich dunite and wehrlite. These are characterised by being coarser in grain than the surrounding olivine-dunite. They therefore reflect the light from cleavage surfaces better than the surrounding rock, which renders them more conspicuous. The local miners in consequence maintain that the dunite carries good values wherever it has a "lively" appearance.

Individual bodies of platinum-rich dunite and wehrlite

range from an inch across to several feet. Often one merely notices what appears to be a big crystal of dark-green olivine or greyish-green diallage.

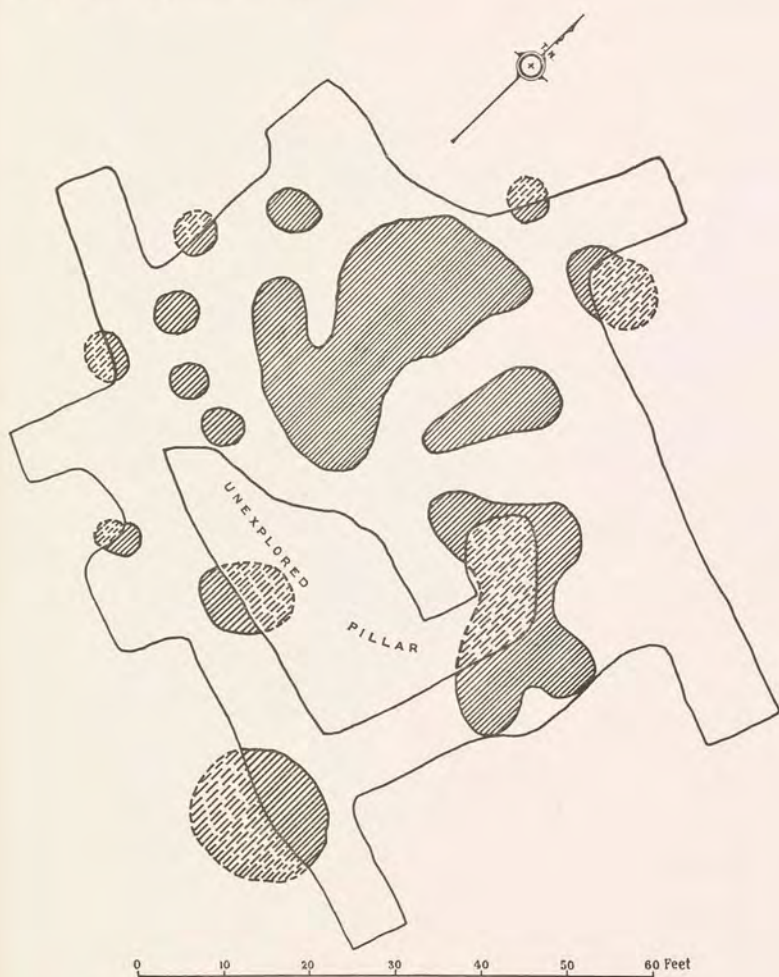


FIG. 9.—Plan of 160-ft. Level, Driekop Platinum Mine.
Showing Pay-Areas (Hatched).

The biggest body so far found was a vein 7 feet long and up to 2 feet wide which was followed downward for 70 feet from the adit level. This however, was situated outside the limits of the "pipe" proper on the south side.

Thin sections of the iron-rich dunite show that it is composed essentially of big interlocking grains of olivine, weathering with a dark-brown rust-like crust. In the purely dunitic facies of the rock magnetite, in small irregular grains, is the only other mineral present. Often, however, the olivine is accompanied by diallage in big greenish-grey crystals up to 1.5 cm. across. These are moulded on the olivine.

The diallage is in places sufficiently abundant to bring the rock within the definition of wehrlite.

Below water-level the minerals named are accompanied by sulphides in specks up to 0.4 cm. across.

Phlogopite and hornblende, which are so conspicuous in the Mooihoek and Onverwacht occurrences, were not noted at Driekop by the writer, though phlogopite is said to occur; nor is chromite ever visible in hand specimens.

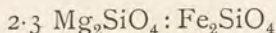
Partial analyses of the iron-rich dunite and of the iron-rich wehrlite are given in columns I. and II. of the accompanying table. The theoretical composition of hyalosiderite corresponding with the formula $2\text{Mg}_2\text{SiO}_4 : \text{Fe}_2\text{SiO}_4$ is given in column III. and that of the Kaiserstuhl, the type occurrence, is given in column IV. These are quoted from Doelter's *Handbuch der Mineralchemie*, vol. ii., part 1, p. 300.

	I.	II.	III.	IV.
SiO_2 . . .	37.92	38.60	37.20	36.72
FeO . . .	25.96	23.61	29.74	29.96
MgO . . .	34.47	32.51	33.06	31.99
CaO . . .	0	3.44	0	0
H_2O . . .	n.d.	n.d.	n.d.	n.d.
	98.35	98.16	100.00	98.67
Specific Gravity .	...	3.465	...	...
Platinum . . .	n.d.	22.0 dwts. per short ton	...	...

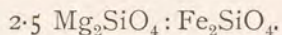
I. Dunite composed of iron-rich olivine approaching hyalosiderite in composition from Upper Quarry, Driekop Mine. Anal., A. McA. Johnston, Goldfields Laboratory.

II. Wehrlite composed of iron-rich olivine and diallage, 300-ft. level, Driekop Mine.

Allowing for the small percentage of iron ore present, the composition of the iron-rich olivine in the dunite represented by Analysis I. is:—



and that of the olivine of the wehrlite represented by Analysis II. is:—



The mineralogical composition of the wehrlite is approximately as follows:—

	Per cent.
Olivine	84.0
Diallage	13.5
Magnetite	0.5

The olivine-dunite within the limits of the "pay bodies" also carries up to 3 dwts. of platinum per ton. It is identical in appearance with that struck in the deeper levels of the Mooihoek and Onverwacht Mines.

At and near the surface it has also in places been completely converted into serpentine. This is replaced by fairly well preserved olivine-dunite at a depth of about 100 feet.

On the 200-ft. level the dunite, though comparatively well preserved, has for some reason suffered disintegration. It is soft and crumbly like rotten sandstone, and can be mined with pick and shovel.

On the 300-ft. level this soft facies of the dunite has disappeared.

Distribution of the Platinum.—The pay limit at the Driekop Mine is round about 2 dwts., and the average grade of the ore sent to the mill is from 3 to 4 dwts.

Within the limits of the "pipe" the platinum values range from 0.3 dwt. to 54 dwts., the extraordinary variation being due to the irregular distribution of the patches of iron-rich dunite and wehrlite in the platinum-poor olivine-dunite.

This is very well shown by the following results of the close sampling of the No. 2 Shaft in the "pipe":—

Width of Section Sampled. Inches.	Assay returned. Dwts. of Platinum Metals per short ton.
122	0.5
72	7.6
96	0.6
42	10.7
48	1.0
48	4.0
48	1.1
168	5.7
72	0.4
<u>716</u>	
Average	<u>3.5</u> dwts.

Origin of the Hortonolite-Dunite and Allied Occurrences.

Much work remains to be done on these deposits before it will be possible to offer satisfactory explanations for the problems that they present.

What has been established definitely is that they and the rocks associated with them exhibit a discordant relation to the pseudostratified members of the Norite Zone and are, in some instances at least, definitely intrusive in them.¹

In certain occurrences (Dwars River) the hortonolite-dunite and associated rocks clearly reached their present position by a process of magmatic emplacement in which the more salic of the intruded rocks were replaced, while the more mafic rocks remained unaffected. In other occurrences the precise manner of replacement is not clear.

There can be no reasonable doubt in the mind of anyone who has studied the various occurrences that both olivine-dunite and hortonolite-dunite are products of the consolidation of liquid dunitic magma fractions. These fractions were evidently of the nature of subsilicic rest-magmas left over from the complex process of differentiation that gave rise to the Differentiated or Critical Zone. In this connection it is of great interest to record that, contrary to the views commonly held by petrologists, it has been definitely established elsewhere² that in a basic magma poor in alkalis, such as that from which the rocks of the Norite Zone separated, progressive crystallisation leads to the formation of a mother-liquor poor in silica and alumina and rich in iron and magnesia.

It was presumably from great residual pockets or intrusive bodies of dunitic mother-liquor that the various occurrences in the Norite Zone of the Bushveld Complex were formed.

In so far as the deposits of the first type are concerned, it is clear that these magmatic solutions underwent further differentiation on cooling and were split, presumably by liquation, into separate iron-poor magnesia-rich and iron-rich magnesia-poor fractions. The iron-rich magma fractions, regardless of whether they gave rise to hortonolite-dunite or

¹ The suggestion of Professor Zavaritzky (64)—if I read him aright—that, as in the Uralian occurrences, the dunites are earlier than the associated norites has nothing to support it, and is definitely opposed by the field evidence.

² Newton, E. T., and Teall, J. J. H., *Q. J. G. S.*, 1897, vol. liii., p. 477.

iron-rich olivine-dunite, crystallised subsequently to those that gave rise to the normal olivine-dunites, or, in other words, retained their fluidity longer. This was probably partly owing to iron-rich olivine having a lower freezing point than iron-poor. The invariably coarser grain, however, and the presence of minerals such as phlogopite, black hornblende and fluorapatite in some of the iron-rich rocks proves that the fractions from which they crystallised were also richer in mineralisers such as HO, F and H₂S. The conclusion is thus inevitable that the iron-rich magma fractions were kept in a fluid state by such mineralisers much longer than would otherwise have been the case and that they ultimately crystallised very slowly under pegmatitic conditions.

Olivine is generally regarded by petrologists as a true pyrogenetic mineral, using the term in its strictest signification. The occurrence, however, of fayalite in lithophyses in rhyolite and obsidian¹ and in pegmatite² is proof that iron-rich olivine can also crystallise under pegmatitic conditions. There is no objection on theoretical grounds to the hypothesis that the pipe-shaped segregations and veins of hortonolite-dunite in olivine-dunite may be of a pegmatitic nature. This hypothesis would, moreover, be in accord with the findings of modern petrologists that pegmatites are especially characteristic of the end stages of magmatic differentiation on a big scale.³ It may be, as the writer has suggested elsewhere, that the hortonolite-dunite and allied rocks represent the basic pegmatitic pole of the differentiation process of which the acid quartz-bearing pegmatitic platiniferous rocks, to be referred to presently, may perhaps represent the acid pole.

In the Mooihoek and Onverwacht occurrences the segregation of the iron-rich and iron-poor fractions was fairly complete. At Driekop it was not, and this occurrence probably owes its peculiar features to the concentration of water and other mineralisers at certain spots where, in consequence, the dunitic magma remained fluid longer than elsewhere, and thus underwent further differentiation with concomitant concentration

¹ Iddings, J. P., and Penfield, S. L., *Am. Journ. Sci.*, 1885, vol. xxx., p. 58.

² Penfield, S. L., and Forbes, E. H., *Z. f. Krystallographie*, 1896, p. 143.

³ Niggli, P., *Gesteins und Mineral Provinzen*, vol. i., p. 33.

of platinum. The incomplete segregation at Driekop as compared with that at the other two occurrences named was, as already indicated, probably due to the fact that the dunitic rest-magma was here much poorer in mineralisers, but it was also presumably poorer in iron.

The platinum metals were everywhere concentrated in the iron-rich fractions or, in other words, in the fractions that remained fluid longest, which suggests either (*a*) that they were more soluble in the iron-rich fractions than in the iron-poor, or (*b*) that they were concentrated with the co-operation of mineralisers.

Of (*a*) the Bushveld dunite deposits appear to afford clear evidence. In regard to (*b*) it is of interest to record that, contrary to the assertions of J. H. L. Vogt (58), recent investigations on the primary dunite deposits of the Urals have led Zavaritzky (64) to the conclusion that both platinum and chromite here originally entered into the composition of hypothetical chemical compounds together with certain volatile substances, and that these compounds formed part of a very mobile residual dunite magma that remained in the liquid state up to the last stage of consolidation when platinum and chromite were separately precipitated.

In this connection it is also to be recalled that in the Mooihoek Mine phlogopite and black hornblende, both of which are rich in hydroxyl and contain fluorine, are good indicators of platinum, and the same was true in the upper levels of the Onverwacht Mine.

If Professor Schneiderhöhn is correct in his conclusions as to the form assumed by platinum in the different ores of the Bushveld Complex, the fact that platinum crystallised in the dunites mainly in the metallic state is due to the poverty of the dunitic rest-magmas in sulphur, arsenic and antimony.

The pegmatite paralleling the main Mooihoek and Onverwacht occurrences, in which minerals such as phlogopite and lustrous black hornblende are the predominant constituents, evidently crystallised from residual magmatic solutions even richer in hydroxyl and mineralisers such as fluorine, and also much richer in potash, than those that gave rise to the main body of hortonolite-dunite.

Zavaritzky (64) has suggested that the analagous veins of diallagite, pegmatitic gabbro and the like in the olivine-

dunites of the Urals were formed by reaction between residual pegmatitic solutions and olivine-dunite. This may also apply to some extent to the veins under consideration, the hornblende and mica being clearly, as in the Merensky Horizon, of the nature of reaction minerals. Similarly, the great zones of phlogopite-bearing diallagite and allied rocks encasing the greater Mooihoek "pipe," and also apparently the Driekop occurrence, may be of the nature of gigantic reaction rims due to the action of residual solutions, containing silica, calcium, potash and various mineralisers, that forced their way up along the contacts of the dunite "pipe" with the rocks encasing it from deeper portions of those subsidiary dunite hearths.

It is only going a step farther to assume that, in the occurrences of hortonolite-dunite in pegmatitic diallagite, the latter may have resulted from the complete alteration, through reaction, of bodies of olivine-dunite that originally encased the hortonolite-dunite. Here, however, we are entirely in the realm of speculation, and it would be idle in the present state of our knowledge to pursue the subject.

Source of the Platinum.—This involves the consideration not only of the ultimate derivation of the platinum contained in the productive occurrences, but of why some of the deposits of hortonolite-dunite contain the metal while the majority are barren.¹ The simplest solution of both problems, and one that at once suggests itself, is that some of the ultrabasic magma fractions from which these dunites crystallised contained small amounts of the metal, while the majority did not, and that the platinum, where present, was indigenous to the magma fractions.

There is, however, clear evidence that these sub-silicic magma fractions were capable of taking up platinum from the rocks traversed, and in some instances did so. In the Rustenburg district, for instance, there are a number of examples of the normally barren hortonolite-dunite and allied rocks of this area becoming platinum-bearing at and near their intersection with the Merensky Horizon, while the Merensky Horizon itself is correspondingly impoverished. Thus, in the main incline on Doornspruit, No. 878, to the north of Rustenburg, a flat-dipping sheet of hortonolite-wehrilite and

¹ The statement by Vogt (58, p. 335) that "the hortonolite magma may in every case carry in silicate solution as much as, say, 5 gm. platinum per ton of magma," evidently rests on a misconception of the facts.

allied rocks cuts at a low angle across the Merensky Horizon. At and near its intersection with the wehrlite the Merensky Horizon, which normally carries an average of 4.6 dwts. over 36 inches, becomes very considerably impoverished, its average platinum content dropping to 1.4 dwts., while the hortonolite-wehrlite, which elsewhere is barren of platinum, is found to contain an average of about 1 dwt. of that metal.

In another instance of the same kind on the farm Kookfontein, No. 337, also to the north of Rustenburg, the total platinum content of the combined body of hortonolite-wehrlite and Merensky reef, expressed in inch.-dwts., that is inches $\times$ pennyweights, was found to be the same as the normal platinum content of the Merensky reef expressed in inch.-dwts., clear proof that the platinum was taken up from the Merensky "Reef."

Part at least of the platinum contained in the productive occurrences of hortonolite-dunite was thus in all probability derived from the adjacent rocks or from rocks traversed at greater depths. Part of it, however, may, by virtue of the richness of some of the occurrences, such as Mooihoek and Onverwacht, in mineralisers, have been indigenous to the magma fractions.

The writer was originally of opinion (31) that the platinum was probably extracted from the rocks traversed by fluorine, notable amounts of which, as we have seen, must have been present in some of these sub-silicic magma fractions.

Against this view, however, are the facts that some of the pegmatitic veins paralleling the main ore body at Mooihoek, while evidently originally very rich in fluorine, are barren of platinum, and that some portions of the Onverwacht "pipe" containing fluorine-bearing phlogopite are also barren.

The productive dunite occurrences are confined to a relatively small area in the western part of the Lydenburg district, lying between lats. S. $24^{\circ} 30'$ and S. $24^{\circ} 39'$ and longs. E. $30^{\circ} 5' 30''$ and $30^{\circ} 9'$. The reason of this is not clear, but the fact of the Onverwacht, Mooihoek, Driekop and some of the lesser occurrences on Maandagshoek and Hendriksplaats being situated practically in a straight line some 9 miles in length, trending approximately N. 35° W.,¹ is certainly strongly suggestive of their alignment along a great subterranean

¹ Cf. Map accompanying the writer's report on the Lydenburg fields (28).

fissure or potential line of weakness of the underlying rocks. The occurrence of Twyfelaar, previously referred to, is situated some miles to the north-east of this line.

II. Occurrence in Normal Olivine-Dunite.

These are of great interest in that they approximate very closely to the classic deposits of the Urals.

Mooihoek and Driekop.—It has already been pointed out that olivine-dunite carrying workable amounts of platinum occurs in both the Mooihoek and Driekop Mines within the limits of the "pay" area, previously referred to. A superficial examination of the platinum-bearing dunite reveals no differences from the barren olivine-dunite. It remains, however, to be more carefully investigated.

At Mooihoek, notable amounts of the metal were also struck outside of the limits of the "pay" pipe in a vertical "waste" winze sunk to the east of it from the 250 to the 350-ft. level (Fig. 5). The winze was carefully sampled at two-foot intervals, and platinum values up to 7 dwts. per short ton were recorded here and there. It was found on closer investigation that these were invariably associated with schlieren and segregations of chromite. The platinum thus occurs under precisely the same conditions as in the Urals where, according to Zavaritsky,¹ notable concentrations of platinum in the olivine-dunites are invariably associated with chromite in nests, shoots, schlieren and vein-like bodies.

The average platinum content of the Mooihoek olivine-dunite is, however, extremely low. Thus, even at the surface where some secondary enrichment might reasonably have been expected, the serpentine derived from it was found to average only 0.45 dwt. to the ton.

Onverwacht.—The olivine-dunite surrounding the Onverwacht "pipe" carries up to 1 dwt. of platinum to the ton. Here, too, the platinum values appear to be associated with local segregations of chromite.

Twyfelaar, No. 172.—In the eastern portion of this farm, some 9 miles north of the Mooihoek occurrence, there was opened up in 1926 a pipe-shaped deposit of olivine-dunite, apparently accompanied by olivine-wehrlite and harzburgite

¹ *Loc. cit.*

and bodies of chromite. The olivine-dunite was carefully sampled and found to carry up to 4 dwts. of platinum per ton. A considerable amount of prospecting work was done on the deposit in the hope that it might reveal segregations of iron-rich dunite similar to those found on Driekop, but these expectations were not realised.

The platinum proved, moreover, to be so sporadically distributed through the olivine-dunite that the deposit was deemed to be unworthy of exploitation. Unfortunately, no analyses of the dunite are available.

Comparison with Uralian Deposits.—The primary platinum deposits of the Urals, as already remarked, find their counterpart in certain of the olivine-dunite occurrences of the Lydenburg district. Hortonolite-dunite is not found in the Urals. The reason for this is probably two-fold, namely,—

- (a) that differentiation did not here go far enough owing to the lack of mineralisers in the magmas that gave rise to the dunites,¹ and
- (b) that these dunitic magmas were much poorer in iron than those from which the Bushveld occurrences crystallised, so that it is doubtful, in any case, whether they could have given rise to such highly ferriferous differentiates.

¹ Cf. Zavaritzky (64).

CHAPTER VIII

PLATINUM DEPOSITS OF THE BUSHVELD COMPLEX (*continued*)

Chromitite Deposits.

SEAMS and lenses of chromitite or chromite rock have a very wide distribution in the lower part of the Norite Zone of the Bushveld Igneous Complex.¹ They range in thickness from an inch to 14 feet and in length from a yard to several miles. In the Lydenburg district the principal deposits, as the writer has pointed out elsewhere (28), occur on two fairly well-defined horizons. Locally, as on Maandagshoek, No. 148, there are three. In the Rustenburg district there are three fairly well-defined chromite horizons.

The chromitite generally presents a characteristic mottled appearance. This is a consequence of its pseudoporphyrific poikilitic texture. It is made up essentially of oval-shaped pseudo-phenocrysts of bronzite from 0.7 to 1.5 cm. in length, crowded with minute chadocrysts of chromite, lying in a granular matrix of somewhat larger chromite grains. The bronzite generally encloses small elongated grains of colourless diopside. Pseudo-phenocrysts of diallage and plagioclase are also sometimes present. The chromic oxide content ranges from 38 to 47 per cent.

It has been known for many years² that the chromitite carries small amounts of platinum, and fairly high assays were occasionally recorded. Speaking generally, however, it was found impossible to repeat these assays. It was only as a result of the systematic prospecting of the lower part of the Norite Zone following on the discovery of the Merensky Horizon that there were located in both the Lydenburg and Rustenburg districts considerable stretches of chromitite carrying, wherever sampled, between 2 and 11 dwts. of platinum metals per ton.

¹ Cf. Wagner, P. A. (25).

² Hall, A. L., and Humphrey, W. A. (1).

These, in both districts, are on the Upper chromite horizon.

In the Lydenburg district the best results have been obtained on the farm Zeekoegat, No. 773, on the Olifants River; on Paschaskraal, No. 126, situated 12 miles south-east of Zeekoegat; on Forest Hill, No. 342, situated 12 miles south-east of Paschaskraal; on Maandagshoek, No. 148, situated 8 miles south of Forest Hill; and on Winterveld, No. 424, some 10 miles south of Maandagshoek.

On Zeekoegat ten consecutive trenches covering a distance of 4400 feet on the strike gave an average value of 3.71 dwts. over 56 inches. One sample taken on this farm over a width of 42 inches by Mr J. E. Vaughan, Inspector of Mines, and assayed in the Government Chemical Laboratory, Johannesburg, returned 11.5 dwts. of platinum metals per short ton.

The deposit on Forest Hill was examined by the writer in October 1925. It lies about one mile to the east of, and roughly 1200 feet vertically below, the Merensky Horizon. The strike is magnetic north and south, and the dip of the chromitite and associated rocks 13 degrees to the east. The deposit has been opened up at intervals of 150 feet in five workings. The sections exposed in Workings "M. 3" and "M. 4" are as follows:—

M. 3.		M. 4.	
Felspathic Bronzitite	. 2 feet	Fine-grained felspathic	
Chromitite	. 3 "	bronzitite	. 6 feet
Rather coarse-grained fels-		Chromitite	. 2 "
pathic bronzitite	. 1 foot	Coarse-grained felspathic	
Spotted norite	. at least 10 feet	bronzitite	. 1 foot
		Spotted norite	. at least 6 feet

Lying about 50 feet vertically above the felspathic bronzitite forming the hanging-wall is a layer of spotted anorthosite. This is well exposed in a shaft that was sunk to intersect the chromitite at depth.

The platinum-bearing chromitite consists, as usual, of oval-shaped grains of bronzite crowded with minute poikilitic enclosures of chromite lying in a scanty matrix of larger grains of that mineral. Locally, however, the rock is interspersed with irregular patches and streaks of coarse-grained chromite, or, more strictly, chromite-picotite, composed of interlocking lustrous crystals ranging from 1 to 2.5 mm. across. This coarse-grained chromite sometimes forms the matrix



1. Portion of upper chromite horizon as exposed on eastern face of Pritchard's Quarry, Kroondal, No. 177, near Rustenburg; shows chromitite (A), bronzitite (B) and norite (C).



2. Seams of chromitite (C) separated by a band of anorthosite (A). Section exposed on Grootboom, No. 186, Lydenburg district.



surrounding individual pseudo-phenocrysts of bronzite, or aggregates of such pseudo-phenocrysts. In addition to the minerals named, the rock contains subordinate amounts of diallage and calcic felspar.

A sample over 3 feet, taken by Mr G. J. Grobler, Assistant Inspector of Mines, in the "M. 3" Working, returned 2 dwts. of platinum per ton.

On Maandagshoek, No. 148, the chromitite of the Upper horizon was found to carry from 1.2 to 5 dwts. per short ton, and that of the Middle horizon from 0.4 to 4.6 dwts. per short ton.

On Winterveld, No. 424, four consecutive trenches, covering a distance of 2200 feet on the strike, gave values averaging 4.06 dwts. over 54 inches.

In the Rustenburg district considerable stretches of the Upper chromite horizon on the farms Kroondal, No. 177, and Klipfontein, No. 538, were found to average about 3 dwts. of platinum metals per ton. A sample taken by the writer on Kroondal and assayed in the Government Laboratory, Johannesburg, returned 6 dwts. of platinum metal per ton.

In the northern part of the Rustenburg district the Upper horizon also in places carries good values, but the platinum metals are very erratic in their distribution.

On Mooihoek, No. 147, which adjoins Maandagshoek, the chromite of the Lower horizon has been shown to have a fairly uniform platinum content of from 1 to 2.1 dwts. per ton.

Form in which Platinum is Present.—Investigations by R. A. Cooper have shown that platinum is contained in the subordinate amounts of silicates present in the ore, the chromite itself being free from platinum. The metal occurs in exceedingly thin plates, wire- and hair-like bodies. These are so small that they float in water. This accounts for the fact that the metal cannot be rendered visible by panning in the ordinary way.

Analyses of the crude platinum from the Lower chromite horizon on Onverwacht, Lydenburg district, prove that it contains only very subordinate amounts of palladium. The same applies to the platinum of the Upper chromite horizon on Kroondal, No. 177, Rustenburg district. On the other hand, the crude platinum of the Upper chromite horizon on

Maandagshoek, No. 148, Lydenburg district, was found to contain 55 per cent. of palladium.

A good deal of work was done on the chromite deposits of different parts of the Complex during 1925 and 1926, but in view of the much better results that have been obtained from the Merensky Horizon in the Rustenburg district operations have since then been suspended on them. At present it appears rather doubtful whether they will ever be worked for their platinum contents.

PLATE XIV



1. Portal of Main Western Incline Shaft, Kroondal-Klipfontein Mine, Rustenburg district.
Shows "Black Turf" overlying Merensky Platinum Horizon.



2. Power Plant of Kroondal-Klipfontein Platinum Mine.



CHAPTER IX

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

Deposits in which Platinum is associated with Magmatic Nickel-Copper-Iron Sulphides.

Deposits of the Vlakfontein Type.—*The Magmatic Nickel Deposits on the Farm Vlakfontein, No. 902, Rustenburg District.*—These deposits, of which a detailed description has been given elsewhere,¹ take the form of isolated pipe- and irregular-shaped masses composed partly of disseminated, partly of poikilitic, and partly of massive or solid sulphide ore. The principal ore minerals are pyrrhotite, pentlandite and chalcopyrite. At and immediately below water-level the pyrrhotite has been largely replaced by marcasite. The ores, which contain appreciable amounts of gold, have been carefully tested for platinum metals, but these have so far only been proved to be present in traces. Where sufficient amounts were found to enable a definite test to be made, it was established by Messrs F. W. Watson and R. A. Cooper that palladium and not platinum is the metal present. Platinum has so far only been found in the oxidised ore of the No. 2 working, where it is present in combination with arsenic in the mineral sperrylite. Judging by such tests as have been made, that mineral is very sparse and erratic in its distribution, even in the ore of this particular occurrence. As a potential source of platinum, the Vlakfontein deposits thus appear to be relatively unimportant.

The outcrops of the deposits take the form of peculiar gossans composed mainly of brightly coloured ferruginous opaline matter. This represents the insoluble colloidal residuum left over from the destruction, mainly through the agency of sulphuric acid, of the sulphide-bearing bronzitite and the rocks adjacent to it.

The country rock of the sulphide deposits, as already stated,

¹ Wagner (26).

is bronzitite. This encloses lenses and sheets of harzburgite and light-coloured anorthositic norite streaked with bands of anorthosite. The writer was led to conclude from his detailed mapping that there was some genetic relation between the distribution of the magmatic nickel deposits and that of the lenses and bands of anorthositic norite. This view receives strong support from what we now know of the sulphidic platinum deposits of the Lydenburg and Potgietersrust districts to which full reference is made in the next chapter.

Occurrences on Rooikoppiesfontein, No. 123, Marico District.—Similar opaline gossans carrying small amounts of nickel and isolated crystals of sperrylite, and thus presumably marking the position of similar bodies of magmatic nickel ore, have been located on the farm named. This is situated about 50 miles west-north-west of Vlakfontein.

Deposit on Goudini, No. 177, Marico District.—On the adjacent farm, Goudini, No. 177, and associated with much the same types of rock as the Vlakfontein deposits, a platinum deposit was opened up in 1925. The metal occurs in coarse-grained bronzitite composed of dull green prismatic individuals of that mineral up to 1.5 cm. in length. The bronzitite is impregnated with secondary limonite and interspersed with small patches of pale blue-green crysocola evidently derived from the oxidation of primary magmatic sulphides. The occurrence does not seem to have any economic significance.

Occurrence on Hartebeestfontein, No. 5, Pretoria District.—Opaline gossans of the same type as those found on Vlakfontein are also known to occur on the northern portion of this farm which is situated 20 miles west-north-west of Pretoria.

CHAPTER X

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

The Merensky Platinum Horizon.

THE deposits on this horizon are among the world's greatest concentrations of mineral wealth and among the most remarkable.

The horizon is in the upper part of the Differentiated Zone. It has been traced, in each case at intervals, for a distance of 180 miles in the Rustenburg and Pretoria districts, 100 miles in the Lydenburg and Peitersburg districts, and some 40 miles in the Potgietersrust district. As it probably persists on the dip for scores of miles the tonnage of ore on it is thus almost beyond calculation.

It attains its most typical development in the Rustenburg and Lydenburg districts, where it lies at a considerable distance above the floor of the Complex, and where the consolidation of the norite magma evidently took place quietly without any disturbance. Here it takes the form of a remarkably persistent, thin layer of dark-coloured platinum-bearing rock or rocks intercalated with a considerable thickness of light-coloured norite and anorthosite.

The platinum-bearing layer and the rocks over- and underlying it conform strictly to the general pseudostratification. They dip inward toward the centre of the Complex at from 6 to 25 degrees and, as previously stated, behave exactly like well-bedded sedimentary strata.

The Merensky Horizon over great stretches is itself quite as regular in its behaviour as a coal seam.

The relationship of the platinum horizon to the associated rocks is shown in the accompanying sections (Figs. 10 and 11) and by the borehole records given in the next chapter. It will be noted that it is overlain at a distance of from 30 to 40 feet by the so-called "Bastard Reef." This latter in some instances

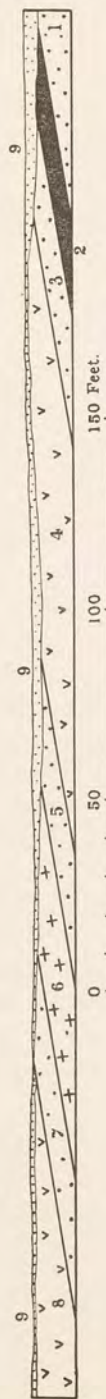


FIG. 10.—Section across Merensky Platinum Horizon and Associated Rocks at the Main Incline on Klipfontein No. 538, Rustenburg District.

- | | | |
|---------------------------------|---------------------------------|---------------------------------|
| 1. Spotted Anorthositic Norite. | 4. Mottled Anorthosite. | 7. Spotted Anorthositic Norite. |
| 2. Merensky Platinum Horizon. | 5. Spotted Anorthositic Norite. | 8. Mottled Anorthosite. |
| 3. Spotted Norite. | 6. Bastard Reef. | 9. "Black Turf" Soil. |

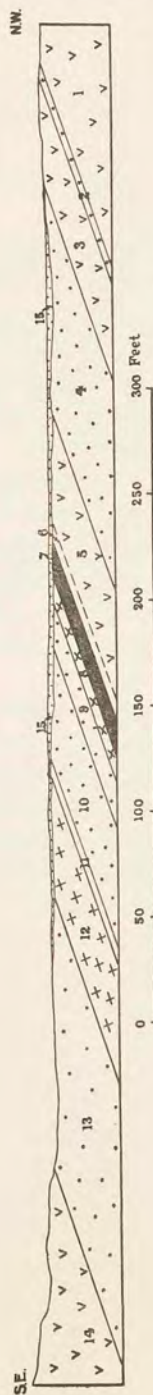


FIG. 11.—Section across Merensky Platinum Horizon and Associated Rocks in No. 2 Incline, Schildpadnest No. 233, Rustenburg District.

- | | | |
|-------------------------|---|----------------------------------|
| 1. Mottled Anorthosite. | 6. Anorthosite in part faintly mottled. | 11. Anorthosite. |
| 2. Spotted Norite. | 7. Merensky Platinum Horizon. | 12. Bastard Reef. |
| 3. Mottled Anorthosite. | 8. Hanging Wall Reef. | 13. Spotted Anorthositic Norite. |
| 4. Spotted Norite. | 9. Spotted Norite. | 14. Mottled Anorthosite. |
| 5. Mottled Anorthosite. | 10. Spotted Anorthosite. | 15. "Black Turf" Soil. |

fairly closely resembles the platinum-bearer, but is either barren of platinum or carries only traces of that metal. It will be referred to again later. It should be stated that the footwall of the Merensky Horizon is generally sharply defined, but the upper portion often merges by imperceptible gradations into the hanging wall norite.

In the northern and southern parts of the Potgietersrust platinum fields the horizon has much the same character as it has in the Rustenburg and Lydenburg fields, but in the very important Zwartfontein sector, to be presently described, where there is evidence not only of considerable movement during the consolidation of the norite magma but of reaction between it and the dolomite, which here constitutes the floor of the Bushveld Complex, the platinum-bearer is in the form of great irregular lenses conforming roughly to the general pseudo-stratification. The lenses often rest directly on a footwall of altered dolomite and, where this is the case, there has been transfusion on a great scale of platinum metals from the norite magma into the altered dolomite which constitutes an important part of the ore bodies. These differences will emerge more clearly from the detailed descriptions which follow, but it may be as well to emphasise them at the outset so as to give the reader a bird's-eye view, as it were, of the horizon as a whole.

It may be as well, too, to state here that the horizon attains its greatest importance in the Rustenburg and Potgietersrust districts, for, while in the Lydenburg district, except for one or two richer sectors, an average of about 2 dwts. per ton of platinum metals is all that can be claimed for even the more regular stretches of the Merensky Horizon, in the Rustenburg district great sectors have been opened up where the average tenor exceeds 6 dwts. over a stoping width, and this is also the average tenor of the great lenticular bodies in the Vaalkop-Zwartfontein sector of the Potgietersrust fields.

Nature and Mineralogy of the Platinum Horizon.—As the horizon presents fairly considerable differences as to the nature and succession of the rocks composing it, it is proposed in the sequel to deal with it on a regional basis. A brief general description of the horizon and of its mineralogy and petrography may, however, first be given.

Where originally discovered by Merensky on the farm

Maandagshoek, No. 148 (Fig. 21), it has the character of a sheet of dark-coloured pyroxenitic pseudoporphyrific diallage norite ranging from 5 to 30 feet in thickness. Where thin, this carries platinum throughout. Where thick, the platinum values are confined to its uppermost portion. It should be stated that the dark-coloured pseudoporphyrific pyroxenitic diallage norite has come to be generally known as "Merensky Reef" or simply as "Merensky."

The horizon maintains the same character over a considerable sector of the Lydenburg fields, the Merensky "Reef," which is variable as to texture and grain, in places enclosing patches of coarse pegmatitic norite or pyroxenite, while segregations of granitic material and lenses of bronzitite are also sometimes in evidence. In the northern and southern parts of the Lydenburg-Pietersburg fields its constitution is different. It is here definitely composite in character (Fig. 23), being made up of distinct layers of Merensky "Reef," coarse pegmatitic norite or felspathic pyroxenite, and chromitite.

This is also the case in the Rustenburg district, where the principal platinum carriers are a layer of coarse felspathic harzburgite or pyroxenite and a thin chromite-rich band that either under- or overlies it (Figs. 16 and 18).

On the Potsgietersrust fields coarse felspathic pyroxenite is again the principal carrier; but here chromite is rare, and, as previously stated, the silicated dolomite flooring the Complex also in places carries very notable amounts of platinum metals. The silicated dolomite and the serpentines derived from it will be described later.

The Merensky "Reef," the coarse felspathic harzburgite or pyroxenite and the "Chrome Band" are everywhere very similar mineralogically. They are made up of different combinations of bronzite or clino-bronzite, diallage, olivine, bytownite-labradorite, hornblende, biotite, chromite, iron ores and the magmatic sulphides mentioned below. Professor Schneiderhöhn shows that plates and flakes of graphite are also widely distributed in the platinum ores. Olivine has so far been definitely recorded only from the Rustenburg district, where the normal coarse felspathic pyroxenite is replaced by coarsely crystalline felspathic harzburgite. Quartz and calcite are occasionally met with.

To the manner of occurrence of the platinum and palladium

in the ores detailed reference will be made later. They are accompanied by subordinate amounts of osmiridium, gold and silver.

The individual minerals enumerated above may next be briefly considered.

Bronzite or Clino-Bronzite.—This is everywhere a principal constituent of the ore. It is a variety poor in iron. Judging by its refractive index— γ is sometimes found to exceed 1.680—and analyses of the ore, the ferrous oxide content ranges from 8 to 10 per cent. It is thus bronzite according to Tschermak's classification of the rhombic pyroxenes which is here followed.¹ It occurs in euhedral and subhedral crystals and big rounded grains, prismatic individuals up to 15 cm. in length being met with in the coarse-grained harzburgite developed in the northern part of the Rustenburg fields. Its colour in the unweathered ore is dark green or very dark brownish-green. In the weathered ore it is dark greenish-brown or brown.

The mineral is always polysynthetically twinned parallel to (010), the extinction angle of the twin lamellae in the symmetrical zone being as much as 8 degrees. It is thus strictly clino-bronzite.

The mineral is almost invariably found to enclose minute, elongated grains of brightly polarising, colourless diopside. These are arranged parallel to the c -axis. It is also sometimes crowded with opaque rods and plates arranged parallel to the c -axis. In the oxidised ore the mineral frequently shows alteration to serpentine and talc with concomitant deposition of secondary iron oxide.

Diallage.—This occurs in lustrous subhedral crystals and anhedral ranging up to 7 cm. across. As the platinum-bearing rocks are everywhere characterised by poikilitic texture and the diallage was, speaking generally, one of the last of the silicates to crystallise, it is generally crowded with chadacrysts of bronzite, biotite, feldspar and chromite. In addition it shows the usual dark interpositions parallel to (100) and (001). In the unweathered ore it is of characteristic brownish-green or greyish-green colour. In the weathered ore it appears dull greyish-brown or yellow.

The mineral has an extinction angle $c : X$ of 42 degrees.

Olivine.—This mineral has only been recognised recently by the writer as a widely distributed constituent of the so-called

¹ *Lehrbuch der Mineralogie*, 6th Edition, pp. 509-510.

felspathic bronzitite of the Merensky Horizon in the Rustenburg district. It is, as a rule, sufficiently abundant to bring that rock within the definition of harzburgite. The olivine is found in coarse poikilitic intergrowth with bronzite, occurring as irregular dark greyish-green to almost black chadacrysts from 0.2 to 1 cm. across, scattered irregularly through big prismatic individuals of bronzite (Fig. 12). Rounded anhedral olivine from 0.5 to 1.5 cm. across and probably in crystallo-



FIG. 12.—Big crystal of Bronzite (1) holding poikilitic enclosures of Olivine (2) and Biotite (3). Merensky Horizon, Schildpadnest No. 233, Rustenburg District. (Two-thirds of Actual Size.)

graphic continuity with some of the chadacrysts occur in the rock adjacent to the bronzite crystals which are moulded on them. The olivine, even in the sulphide ore at a depth of 400 feet on the incline, shows fairly advanced serpentinisation with development of a typical mesh structure and separation of much secondary magnetite. Olivine is also probably present in the ore of the Merensky Horizon as developed in the Lydenburg district, as in a thin section of a pegmatitic segregation in the normal Merensky "Reef" on Helena, No. 220, the writer came across serpentine pseudomorphs the outlines of which recalled those of olivine crystals.

Plagioclase. — This is sometimes euhedral in tabular crystals and sometimes anhedral in big irregular grains up to 6 cm. across, generally holding rounded poikilitic inclusions of bronzite. Its colour ranges from white through greyish-white and yellowish-white to grey or greyish-pink.

It is always polysynthetically twinned according to the albite and pericline laws. The crystals are generally irregularly fractured. They often show strain shadows and sometimes incipient granulation.

Chemically it is labradorite-bytownite or bytownite-labradorite, the composition ranging from $Ab_{37}An_{63}$ to $Ab_{30}An_{70}$.

An analysis of a specimen of the mineral from the

Klipfontein Mine in the Rustenburg district gave the following result:—

	Per cent.
SiO ₂	52.8
Al ₂ O ₃	30.2
CaO	12.5
Na ₂ O	4.45
	99.95
Specific gravity	2.70

Anal., P. Trotzig (92).

The plagioclase is as a rule fairly fresh, but sometimes shows alteration to calcite, chlorite and epidote. In the oxidised zone it is often stained green by malachite and brown by secondary limonite.

Brown Mica.—Flakes and plates of brown mica are always in evidence though never very common. It appears to be a variety of biotite, with a small axial angle. The biotite also sometimes holds poikilitic enclosures of bronzite. It is often intimately associated with the magmatic sulphides and is sometimes seen to be idiomorphic toward them. It will be shown later that both the biotite and the hornblende are of the nature of "reaction minerals."

Hornblende.—A magmatic hornblende strongly pleochroic in shades of green and brown is always present, and locally abundant. It is generally found rimming diallage and, more rarely, bronzite from which it has clearly developed. Sometimes the replacement of these minerals is almost complete and one finds apparently homogeneous crystals of hornblende up to 1 cm. across. These are often idiomorphic towards the interstitial sulphides. The hornblende also occurs in parallel intergrowth with biotite. It is, as already stated, strongly pleochroic;

Z = deep-brown or reddish-brown;

X and Y = yellowish-green.

The extinction angle averages about 17 degrees.

Both the hornblende and the biotite clearly belong to a comparatively late stage in the crystallisation in the rocks in which they occur. They probably owe their origin to reaction between the earlier pyroxenes and the magmatic residuum left over after their separation. The two minerals are frequently

seen to be intimately associated with the magmatic sulphides. In some thin sections there is clear proof that they crystallised before the sulphides. In others the reverse is true, the sulphides being enclosed in hornblende and biotite toward which they are sometimes idiomorphic. These facts can only be reconciled on the assumption that the sulphides, hornblende and biotite belong to much the same period of crystallisation: the sulphides, though they, as will be shown, probably began to separate at a very early stage, being by virtue of their low freezing point end-stage consolidation products like hornblende and biotite.

While the intimate association between these minerals and the sulphides is not entirely fortuitous, there is nothing to suggest that the formation of the hornblende or biotite was a direct consequence of, or a necessary preliminary to, the separation of the sulphides. Numerous instances were observed of sulphides in direct contact with unaltered diallage and bronzite, and of the development of hornblende and biotite where no sulphides are present.

Chromite.—Chromite occurs in well-formed octahedral crystals up to 1 mm. across and irregular rounded grains. It is slightly magnetic and is really chromite-picotite as, in addition to ferric oxide and chromic oxide, it always contains notable amounts of magnesia and alumina. It was invariably the first mineral to crystallise, being enclosed in all the others.

Magnetite.—Magnetite is present in minor amounts generally in irregular grains and more rarely in imperfect octahedra.

Quartz.—Patches of quartz up to 1 cm. across were noted in patches of granitic nature in the Merensky "Reef" on Helena, No. 220, Lydenburg District, and patches of quartz were also noticed in the Merensky "Reef" on the adjoining farm Der Brochen, No. 226. Trotzig (92) figures a vermicular quartz intergrown with felspar in the ore of Helena.

Orthoclase.—Turbid greyish-pink orthoclase was noted in a granitic segregation in the platinum-bearer on Helena.

Tourmaline.—Crystals of lustrous tourmaline, up to 0.8 cm. across, were noted in a segregation composed of quartz, phlogopite, calcite and serpentine occurring in the ore of the horizon on Helena.

Calcite.—Patches of white calcite were noted in association with quartz in the Merensky "Reef" on Helena, the mineral

occurring in a portion of the "Reef" rich in phlogopite, hornblende and sulphides. It is moulded on the silicates and is evidently a product of the hydrothermal stage of the consolidation of the platinum-bearing rock.

Magmatic Sulphides.—Below the limits of the zone of oxidation which extends to a depth of from 15 to 1000 feet measured on the incline, corresponding with a vertical depth of from 5 to 100 feet, the several types of platinum-bearing rock are everywhere found to be more or less uniformly interspersed with specks and patches of primary sulphides. These range from 0.001 mm. to 0.3 cm. in diameter. The larger sulphide specks and patches are definitely interstitial to the silicates and moulded on them, but as will be pointed out, minute globular and irregularly shaped sulphide specks also occur included in the silicates, particularly in the diallage and feldspar. They are sometimes orientated along cleavages and crystallographic planes. More usually, however, they are irregularly scattered through their hosts. Where there is evidence of movement during consolidation the magmatic sulphides are occasionally seen to form well-defined veins.

The percentage of sulphides present ranges from 2 to 3 per cent. Exceptionally, however, it is much higher. The larger sulphide grains and inclusions are always seen in polished sections to be composite in character, being made up of complex intergrowths of brownish-bronze coloured pyrrhotite, paler bronze-coloured pentlandite and brass-coloured chalcopyrite; these minerals, according to the investigations of Professor Schneiderhöhn, being accompanied by an unidentified nickel-iron mineral, subordinate amounts of cubanite or chalmersite and in the ores of the Rustenburg district by yellow nickeliferous pyrite. According to the same authority secondary millerite is sometimes present.

Special interest attaches to the nickeliferous pyrite, the presence of this mineral having only recently been established by Professor Schneiderhöhn. It is probably widely distributed in the ore of the Merensky Horizon as developed in the Rustenburg district. It occurs in ragged residual patches enclosed in pyrrhotite and pentlandite. It resembles pyrite in appearance and properties, but contains notable amounts of nickel. It has, apparently, the composition $(\text{Fe}, \text{Ni})\text{S}_2$.

Pentlandite is distinguished in hand specimens by its hackly

fracture and in polished sections by its resistance to etching by hot hydrochloric acid. The mineral is present in two generations. That belonging to the older occurs as largish grains and thick impersistent shells rimming rounded grains of pyrrhotite; also as wedge-shaped inclusions in that mineral, these being sometimes idiomorphic towards it on one side. More rarely shells of pyrrhotite are found separating grains of pentlandite from the surrounding pyroxene. Sometimes an irregularly elongated sulphide patch will show pentlandite at one end and chalcopyrite at the other, the middle part consisting of pyrrhotite and nickeliferous pyrite. The pentlandite always exhibits characteristic octahedral partings which are sometimes occupied by secondary silicates. The pentlandite of the second generation, as will be described by Professor Schneiderhöhn, occurs as minute orientated inclusions in the pyrrhotite. Its origin is attributed by him to unmixing in the solid.

Chalcopyrite occurs in irregular shells surrounding composite grains of pyrrhotite, nickeliferous pyrite and pentlandite, proving that it was generally the last sulphide to crystallise. It also occurs in irregular patches and areas intergrown with pyrrhotite and pentlandite, and finally as minute inclusions in the silicates. It is subordinate to the nickel-bearing sulphides, as is indicated by the fact that in the platinum-bearing rocks the ratio of nickel to copper is roughly as 2 : 1.

Small amounts of cobalt are also present. Professor Schneiderhöhn has shown that it is associated mainly with the pyrrhotite, but the precise form in which it is present is not known. D. C. Sharpstone¹ claims to have identified arsenopyrite in the ore of the Kroondal-Klipfontein Mine. The writer has been unable to confirm this identification, but in a specimen of ore from the Kroondal Mine submitted to him by Mr G. H. Beatty he identified a grain of what he took to be löllingite.

Professor Schneiderhöhn deals so fully and lucidly in Chapter XVII. with the magmatic sulphides and their textural and genetic relations that it would be superfluous to say any more about them here. A few supplementary remarks must, however, be made in regard to the minute globular sulphide inclusions which are sometimes quite common

¹ Report (unpublished) on the Ores of the Eerstegeluk Platinum Mines, Ltd.

in the silicates. They range in diameter from 0.001 mm. to 0.097 mm., the average diameter being about 0.04 mm. They are, as already indicated, spherical or ellipsoidal in form, but some of them appear to be subhedral. The bigger globules are composite in character and made up of the same intergrowths as the interstitial grains. They often lie completely isolated in perfectly fresh unaltered silicates away from any cracks and cleavages, and are also sometimes seen to be orientated parallel to definite crystallographic planes. The occurrence of the magmatic sulphides in these globules appears to the writer to be of great importance from the genetic point of view, as there can be no question that we have to do here with droplets of matte that separated from the magma before the silicates began to crystallise. Similar globules and droplets have been noted before by the writer. Their presence supports the view put forward by J. H. L. Vogt, and elaborated by Schneiderhöhn, that the magmatic sulphides, though they only solidified subsequently to the silicates, began to separate before them, and further, that the initial separation or liquation took place at a very high temperature.

Platinum and other Precious Metals.

From the economic point of view interest centres mainly in the platinum and other precious metals contained in the ores of the Merensky Horizon, though considerable amounts of nickel and copper and appreciable quantities of gold will be recovered as by-products.

The platinum metals of the ores range from a trace to as much as 13 ounces per ton in picked specimens. It will be shown that over considerable sectors of the horizon in the Rustenburg district, where it is being systematically opened up, it carries an average of 6 dwts. of platinum metals over a stoping width of 30 inches, and an average of from 10 to 12 dwts. over a milling width of 12 inches.

Platinum is accompanied in these ores by considerable amounts of palladium, the proportion of palladium to platinum ranging from 11.8:76.3 to 62:38, the proportion being the highest on the Potgietersrust fields. The table on page 110, shows the relative proportions of the platinum metals and gold in the crude platinum of the Merensky Horizon in the Rustenburg and Potgietersrust districts.

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The ratio of platinum to palladium is from 7 to 10 per cent. higher in the oxidised zone than in the sulphide zone, the palladium being clearly more susceptible to leaching by oxygenated surface waters.

	Klipfontein-Kroondal Mine, Rustenburg.		Schildpadnest, No. 233, Rustenburg.	Elandsfontein, No. 820, Rustenburg.	Forest Hill, No. 342, Lydenburg.	Helena, No. 220, Lydenburg.
	Oxidised Ore.	Sulphide Ore. ²	Oxidised Ore.	Sulphide Ore.	Oxidised Ore.	Sulphide Ore.
Pt . . .	77.5	66	76.3	70.0	73.0	74.13
Pd . . .	15.2	25	11.8	20.0	20.0	24.91
Rh . . .	2.0	4	1.70	...	...	...
Ir . . .	1.3	...	1.18	...	...	...
Osmiridium	0.95	1	4.50	5.0	2.0	0.90
Gold . . .	2.57	4	1.90	5.0 ³	4.0 ³	...
Totals . .	99.42 ¹	100	97.38	100.0	99.0	99.94
Analyst .	L. Heymann	H. R. Adam	L. Heymann	L. Heymann	...	F. Krupp & Co., Grusonwerk

¹ The ore in addition contains about 2 per cent. of silver.

² Mean of several analyses.

³ Gold and other platinum metals.

In addition to palladium, subordinate amounts of rhodium, osmiridium, gold and silver are present. The ore is locally very rich in gold. Thus, a picked sample from the Rustenburg Townlands assayed 42 dwts. per ton of ore. As a rule, however, only a fraction of a pennyweight is present. Coarse supergene gold is sometimes visible to the naked eye in the oxidised ore. Osmiridium is present in minute hexagonal plates in the concentrates obtained from the treatment of ore.

One of the most reliable analyses of the crude platinum so far made was of 347 gm. of bullion recovered by the metallurgists of the Grusonwerk (F. Krupp, Magdeburg) from a bulk sample of ore from the Schildpadnest Mine, Rustenburg district. This consisted partly of sulphide and partly of oxidised ore in the ratio of 2 to 1.

The bullion was analysed and found to contain :—

281 gm. of platinum metals,
60 gm. of sulphur,
6 gm. of gold.

The platinum metals were found to be present in the following proportions:—

	Per cent.
Pt	73·4
Pd	20·8
Rh	5·3
Osmiridium	0·5
Total	<u>100·0</u>

On the Potgietersrust fields the ratio of palladium to platinum is, as already stated, higher than in the Rustenburg and Lydenburg districts. In the sulphidic ore of the Vaalkop sector, to be presently dealt with, it is as high as 62:38. In the Zwartfontein Central sector it is lower, the ratio of palladium to platinum being as 44:55 in the oxidised ore and as 50:48 in the sulphide ore.

The estimated amounts of platinum, palladium and other metals in the concentrates recovered during the quarter ended 31st December 1928, at the Potgietersrust Platinums' treatment plant running on ore from the Zwartfontein Central sector, were actually as follows:—

Pt	1045 ounces
Pd	796 „
Other platinum group metals	44 „
Gold	76 „
Nickel	6·8 tons
Copper	3·8 „

It should be stated that oxidised and sulphide ores are treated together in the proportion of 2 to 1.

Silver is generally quite subordinate to platinum in these ores, as a rule only making up about 2 per cent. of the bullion. The one exception is the farm Helena, No. 220 (old St Edmunds) in the Lydenburg district, where the metal is relatively abundant, the ratio of silver to platinum in the bullion being as 3 to 4.

The Form in which Platinum Metals are present.

It has already been stated that platinum is present in the sulphidic ore of the Merensky Horizon as cooperite, which is apparently replaced in the Lydenburg district by sperrylite; and, further, that there are present minute plates of osmiridium and grains of gold.

Only part, however, of the platinum proved by assay to be present is represented by cooperite and sperrylite and can be recovered by concentration. This applies with even greater force to the palladium. This metal is generally present in the proportion of 1 to 3 or 4 parts of platinum, and yet the gravity concentrates obtained by careful tests of the ores are practically free from palladium. These facts led the writer to conclude that part, at least, of the platinum and the bulk of the palladium must be present in some other form or combination. To ascertain whether the microscope could afford confirmation or otherwise of this view, he submitted a suite of specimens of sulphide ore from the Schildpadnest Mine to Professor H. Schneiderhöhn, Freiburg.

The ore submitted, according to assays made by Dr L. Heymann, Johannesburg, carried an average of 5 dwts. of platinum metals per ton, while Messrs F. Krupp found an average of 4.7 dwts. It should be stated, however, that these assays referred to bulk samples of ore and not to the individual specimens which Professor Schneiderhöhn examined.

Professor Schneiderhöhn, the results of whose elaborate investigation are fully set forth in Chapter XXVII., prepared a large number of polished sections of the ore which he examined under the highest powers of magnification. And yet he did not succeed in identifying so much as a speck of platinum, cooperite, sperrylite or stibiopalladinite.

He next subjected small grains of all the minerals entering into the composition of the ore to spectrographic analysis, and as a result of the most carefully conducted measurements, came to the conclusion that the platinum metals are contained in a state of isomorphous solid solution in the earlier formed sulphides present in the ores.

These conclusions are of the greatest interest and importance both from the theoretical and practical points of view. They explain, for instance, why simple gravity concentration of the sulphidic ores of the Merensky Horizon was a complete failure.

It must be emphasised, however, that the conclusions are based only on the material examined by Professor Schneiderhöhn. The writer has actually seen cooperite imbedded in a specimen of sulphidic ore from the Kroondal-Klipfontein Mine, Rustenburg, and sperrylite in a specimen

from Helena, No. 220, in the Lydenburg district. Only part of the platinum contained in the ore can therefore be present in solid solution in the sulphides. It is probable that when the concentration of the metal exceeded a certain limit it crystallised out as cooperite or sperrylite, provided that arsenic and sulphur were present. When the limit was not exceeded it remained in solid solution.

Plates of osmiridium are, as already stated, also visible in the concentrates obtained from the treatment of the sulphide ore. On the other hand, no definite palladium mineral has been identified in the ore of the Merensky Horizon. The bulk of that metal is thus probably in solid solution in the sulphides.

Effect of Movements during and subsequent to Consolidation.—There is overwhelming evidence to show that in these ores the sulphides crystallised long subsequent to, or, in other words, maintained their fluidity long after the accompanying silicates. Where, as sometimes happened, there was fissuring during consolidation, they and the platinum metals associated with them were squeezed out into cracks and fissures in the adjacent or underlying rocks. The most striking illustration of this is at Elandsfontein, No. 374, in the Pretoria district, which occurrence will be dealt with later.

Another very interesting phenomenon may here briefly be referred to. Wherever there is evidence of the Merensky Horizon having been subjected to compressive stress during the final stages of consolidation—such stress being manifested by minor folds, rolls or shear-zones—there is a marked drop in values and the platinum metals sometimes disappear altogether without leaving a trace behind, whereas the sulphides may in such instances be present in the same proportions as elsewhere. This suggests that part at least of the platinum metals was in solution in the sulphides in a gaseous state even after the sulphides had crystallised, and that they remained in this state until a comparatively low temperature had been reached, when, as suggested by the investigations of Professor Schneiderhöhn, they entered into solid solution in sulphides. It may have been this portion of the platinum metals that entered into solid solution.

It should be added that there are also many examples of minor folds and of faults and fractures that did not in any way

affect the sulphides or the platinum values. Such are clearly due to movements that took place after both the sulphides and the platinum metals had consolidated.

Petrography of the Platinum-Bearing Rocks.—A brief account may next be given of the petrography of the main types of platinum-bearing rocks found on the Merensky Horizon. They are:

- (1) Pseudoporphyrific pyroxenitic diallage norite, generally known as "Merensky Reef."
- (2) Coarse-grained felspathic pyroxenite, the place of which is taken in the Rustenburg district by coarsely crystalline felspathic harzburgite.
- (3) Chromitite or felspathic chromitite constituting the chrome bands that in many localities are an important feature of the horizon.

All these types are conspicuously poikilitic in texture. Indeed, that texture may be said to be the characteristic of the rocks of the Merensky Horizon.

(1) *The Merensky "Reef."*—This everywhere presents the same features. It is made up of lustrous subhedral pseudo-phenocrysts of diallage, from 0.8 to 6 cm. in length, and enclosing chadacrysts of bronzite and biotite lying in a granular mottled base of bronzite and labradorite-bytownite accompanied by plates of brown mica and minute crystals of chromite and magnetite. The bronzite of the ground mass forms holohedral and subhedral prismatic individuals up to 6 cm. long. The labradorite-bytownite, which is irregularly distributed, forms anhedral up to 1.5 cm. across, holding poikilitic inclusions of bronzite. Thin sections usually reveal the presence of considerable amounts of magmatic hornblende, the manner of occurrence of that mineral having already been indicated. The bronzite was the earliest of the silicates to crystallise. The diallage is moulded on the bronzite and the plagioclase is generally moulded on the diallage. Sometimes, however, the crystallisation of the plagioclase appears to have preceded that of the diallage.

The Merensky "Reef," as already indicated, is extraordinarily variable as to texture, grain and composition. The normal pseudoporphyrific pyroxenitic norite is often seen to enclose

irregular lenses of almost pure bronzitite, or patches of coarse-grained pegmatitic diallage norite, or of labradorite-bronzite-biotite rock. Segregations composed of quartz, felspar and phlogopite, or of quartz, bronzite and acid plagioclase, or of quartz, phlogopite, tourmaline, calcite, serpentine and talc are also sometimes seen. In one of them an interesting poikilitic intergrowth between quartz and bronzite was noted.

(2) *Coarse-Grained Felspathic Pyroxenite and Harzburgite.*—

This is a handsome coarse-grained rock composed of bronzite, diallage, labradorite-bytownite, hornblende, chromite and magnetite, which below the zone of weathering are accompanied by the usual sulphide intergrowths. As normally developed it consists predominantly of clino-bronzite. Sometimes, however, plagioclase and pyroxene are present in almost equal proportions, and the rock then becomes a norite.

The rock is normally very coarsely crystalline, the maximum diameter of grain ranging from 3 cm. to 15 cm. As a rule the silicates are in poikilitic intergrowth, big individuals of diallage and plagioclase holding chadocrysts of bronzite. The bronzite, apart from its occurrence thus enclosed, forms big subhedra up to 15 cm. in length. The diallage often shows an outer shell of hornblende. The labradorite-bytownite when abundant occurs, as stated above, in big anhedral holding poikilitic inclusions of bronzite. Usually, however, it is interstitial to the pyroxenes forming wedge-shaped and irregular vein-like bodies between them.

The silicates are characteristically highly fractured. The fractures, in part at least, are of pre-sulphide age, as they are frequently occupied by sulphide veinlets. The chromite is, as a rule, partially distributed through the rock in well-formed octahedral crystals enclosed in the silicates. In some localities where the segregation of the chromite into the Chrome Band has been imperfect, the lower part of the layer of felspathic pyroxenite is thickly peppered with small crystals and grains of the mineral. On weathering, the felspathic pyroxenite generally assumes a peculiar greenish-yellow or yellowish-green colour, and is often seen to be interspersed with patches of secondary dense white magnetite or to be traversed by seams and veins of that mineral. Other secondary minerals resulting from the weathering of the rock are serpentine, talc, chlorite and limonite.

Felspathic Harzburgite.—In the Rustenburg district the coarse-grained rock over and underlying the Chrome Band, and originally taken to be felspathic bronzitite, has been found on more careful microscopic examination to be coarse-grained poikilitic felspathic harzburgite composed, in order of abundance, of bronzite, olivine, bytownite-labradorite, magmatic sulphides, biotite, chromite, and magnetite. Clino-bronzite, which is the predominant constituent, occurs in irregular prismatic individuals up to 15 cm., holding irregular chadocrysts of olivine.

The plagioclase, which has a peculiar greyish-pink colour, occurs in elongated interstitial grains and patches up to 3 cm.

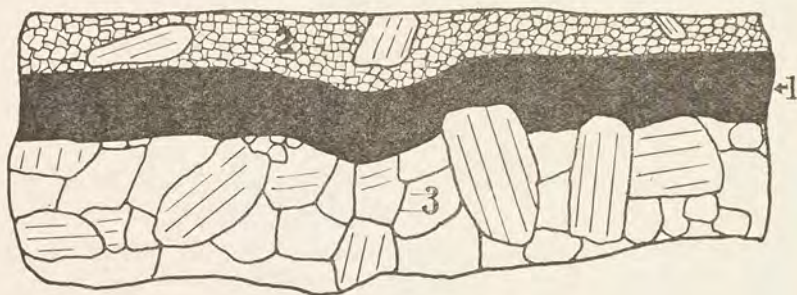


FIG. 13.—Section across Chrome Band(1), underlying Merensky "Reef"(2), overlying felspathic Harzburgite(3). Schildpadnest No. 233, Rustenburg. (Actual Size.)

in length. Biotite, in irregular flakes and plates, is intergrown with the olivine and bronzite and enclosed in the felspar. In some of the sectors of the mine workings on the farms named the minerals, above enumerated, are accompanied by diallage.

(3) *Chromitite.*—The Chrome Band or bands, which are a feature of the horizon in the Rustenburg district and parts of the Lydenburg district, are somewhat variable in character. They sometimes consist, as in the northern part of the Rustenburg district, almost entirely of interlocking grains and crystals of chromite with only subordinate amounts of interstitial pyroxenes. In other localities, as in the neighbourhood of Rustenburg, they are made up of grains and crystals of chromite scattered thickly and uniformly through a base composed of big interlocking crystals of plagioclase, diallage

and bronzite, the first-named mineral generally predominating. In yet other localities the rock exhibits, like the normal chromitite of the Bushveld Complex, a pseudoporphyritic poikilitic texture, being made up of pseudo-phenocrysts of bronzite and diallage, crowded with small chromite chadocrysts, scattered through a base of larger interlocking chromite grains and crystals. In the sulphide zone isolated sulphide grains and specks are always present.

The chrome bands, as developed in different localities, also vary considerably in grain. In the south-eastern part of the

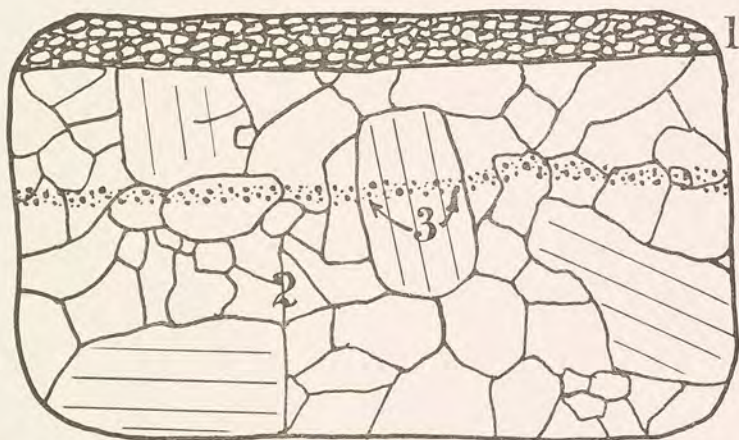


FIG. 14.—Shows Chrome Band traversing bronzite and felspar crystals in felspathic bronzitite, Helena, No. 220, Lydenburg District. (Actual Size.)

1. Hanging-wall norite. 2. Felspathic bronzitite. 3. Chrome Band.

Rustenburg district, the individual chromite crystals rarely exceed 0.25 mm. in diameter, whereas, in the northern part of the same district, the chromite is made up of interlocking grains and crystals up to 3 mm. across.

The chrome bands are generally subject to rapid variations in thickness, and big crystals of bronzite are frequently seen to project into them (Fig. 13).

On Helena, No. 220, in the Lydenburg district, where the Chrome Band is thin and consists, as a rule, of scattered grains of the mineral, it is often seen to cut indiscriminately across the large crystals of bronzite and other silicates present (Fig. 14). As the chromite is distinctly of earlier crystallisation than the associated silicates, we must conclude that the chromite grains,

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Table of Analyses of Ore of the

	I.	II.	III.	IV.
SiO ₂	51.50	52.50	50.38	49.81
TiO ₂	0.20	0.15	0.23	0.30
Al ₂ O ₃	5.40	6.90	4.47	4.17
Cr ₂ O ₃	n.d.	0.45	1.43	1.14
Fe ₂ O ₃	2.40	4.50	} 14.48	{ 14.92
FeO	11.00	6.80		
MnO	0.15	nil	0.34 ²	0.34 ²
MgO	21.95	23.25	20.73	20.84
CaO	5.40	4.30	5.28	5.03
K ₂ O	trace	trace	} 1.21	{ 1.10
Na ₂ O	0.90	0.45		
P ₂ O ₅	0.10	slight trace	0.04	0.05
CO ₂	nil	nil	1.04	1.26
S	...	...	0.14	0.64
As	...	...	0.17	0.12
Sb	...	...	0.17	0.12
Ni	trace	0.10	0.26	0.25
Cu	...	...	0.10	0.08
H ₂ O +	0.40	0.60	0.05	0.04
H ₂ O -	0.45	0.50	n.d.	n.d.
Totals	99.85 ¹	100.50	100.52	99.56
Less oxygen equivalent of sulphur	...	...	...	...
Totals	...	...	...	...
Specific gravity	3.200	3.215	...	...
Pt (dwts. per short ton)	2.0	...	4.17	5.0
Au (" ")	...	...	...	...

¹ The symbol of this rock according to the American Classification is IV. 1.1.1.2.² Mn₃O₄.

I. Oxidised "Merensky Reef," Winnarshoek, No. 349, Lydenburg District. Analyst, H. G. Weall; quoted Wagner (28).

II. Oxidised "Merensky Reef," Uitvalgrond, No. 334, Rustenburg District. H. G. Weall; quoted Wagner (32).

III. Composite sample of oxidised ore, No. 2 Incline, Schildpadnest, No. 233, Rustenburg District. Analysed in Laboratory of Messrs Fried. Krupp Grusonwerk, Magdeburg.

IV. Composite sample of sulphide ore, vertical shaft, Schildpadnest, No. 233, Rustenburg District. Anal. *ibid*.

V. Sulphide "Merensky Reef." Dwaarsrivier, No. 86, Lydenburg District. Analyst, H. G. Weall; quoted Wagner (31).

Merensky Platinum Horizon.

V.	VI.	VII.	VIII.	IX.	X.
50.50	49.55	48.70	47.38	51.22	51.19
0.25	0.36	0.26	} 9.91 {	0.41	0.22
6.00	8.04	5.52		7.85	5.14
0.55	1.50	1.60	1.19	0.20	0.16
4.15 +	8.87 +	11.79	} 13.82 {	1.76	2.18
9.40 +	2.47	1.70		12.24	12.60
0.15	0.20 ²	0.90 ²	0.27 ²	0.14	0.16
21.90	17.40	20.00	18.07	17.21	21.78
4.40	6.30	4.70	5.86	5.70	5.36
trace	} 1.30	1.22	n.d. {	0.40	0.32
1.25				0.70	0.35
0.10	1.40	1.70	n.d.	trace	0.08
0.15	1.35	1.38	...	0.28	nil
1.35	0.63	0.20	0.28	0.69	0.06
...	0.06	0.06	0.07	...	...
...	0.10	0.03	...	...	...
0.40	0.30	0.30	0.37	0.22	0.08
0.14	0.20	0.20	0.23	0.18	0.05
0.65	} n.d. {	0.10	0.17	0.75	0.61
0.15		...	...	0.23	0.17
101.49	100.03	100.36	97.56	100.18	100.51
0.70	...	...	...	0.34	...
100.79	...	...	...	99.84	...
...	...	...	...	...	...
3.3	7.7	7.06	6.2	...	...
...	0.26	0.39	0.18	...	...

² Mn₃O₄.

VI. Sulphidic ore, Merensky Horizon, Klipfontein, No. 538, Rustenburg District. Analyst, P. Trotzig (92).

VII. Oxidised ore, Merensky Platinum Horizon, Klipfontein, No. 538, Rustenburg District. Analyst, P. Trotzig (92).

VIII. Oxidised ore, Merensky Platinum Horizon, Waterval, No. 1023, Rustenburg District. Analyst, P. Trotzig (92).

IX. Moderately coarse-grained felspathic pyroxenite (platinum-bearing), Sandsloot, No. 276, Potgietersrust District. Analyst, L. Möser, quoted by E. Reuning (59).

X. Medium-grained "Merensky Reef," Zwartfontein, No. 121, Potgietersrust District. Analyst, L. Möser, quoted by E. Reuning (59).

after being formed, here remained suspended in the magma at a certain level and that the silicates crystallised round them.

Chemical Composition of the Platinum-Bearing Rocks.—

A number of complete analyses are available of the different types of oxidised and sulphidic ore occurring at widely separated localities on the Merensky Horizon. They are tabulated on pp. 118-19. The platinum content of the rock analysed is given wherever it is known. The gold content is also given in one or two instances.

The analyses not only prove that the Merensky "Reef" itself (Anal. I., II., V. and X.) is remarkably uniform in composition—that might have been expected—but that the composition of the platinum-bearer, whether made up entirely of Merensky "Reef" or whether composite in character and made up of several types of rock, is also, in some instances at least, very uniform.

Thus, in the table, column I. contains an analysis of the Merensky "Reef" making up the entire thickness of the horizon on Winnaarshoek, No. 349, in the Lydenburg district. Columns III. and IV., on the other hand, contain analyses of representative composite samples over 42 inches of the ore of the Merensky Horizon on the farm Schildpadnest, the samples including 6 inches of Merensky "Reef," 1 inch of Chrome Band and 35 inches of felspathic pyroxenite. Yet it will be noticed that the analyses are very similar, the only difference noted being that the Schildpadnest ore contains more chromic oxide. This identity of composition indicates that the magma fractions that gave rise to the platinum horizon in the two areas were practically identical in composition, but that in the Rustenburg district the differentiation went farther. It should be stated that the distance from Winnaarshoek to Schildpadnest measured along the strike of the rocks of the Norite Zone is something like 350 miles.

The analyses of the ore from Klipfontein, No. 538, Rustenburg district, column VI., and from Waterval, No. 1023, column VIII., differ somewhat from those of the Schildpadnest ore. This may be due to the fact that the samples from the two farms named were not representative of the horizon as a whole, which is here also composite in character.

It has already been stated that in some parts of the Lydenburg district quartz enters into the constitution of the

Merensky "Reef." A partial analysis of the quartz-bearing facies of the "reef" from the farm Der Brochen, No. 226, Lydenburg district, gave the following result:—

	Per cent.
SiO ₂	62.2
Al ₂ O ₃ }	17.30
+ Fe ₂ O ₃ }	
- FeO }	
MgO	14.78
CaO	4.03
S	0.72
Cu	0.14
Ni	0.17
H ₂ O	0.20

Analyst, R. A. Cooper.

The alkalis, unfortunately, were not determined.

Segregation Veins.

At numerous localities narrow quartz-bearing veins of rather unusual composition are found cutting the Merensky Horizon. They vary in thickness from a few mm. to 5 or 6 cm. and are generally vertical or steeply inclined. They never extend far beyond the limits of the horizon, generally wedging out in the hanging wall norite or footwall anorthosite. The veins are coarsely crystalline in texture, and are characterised by their richness in quartz and brown mica which occurs in crystals up to $1\frac{1}{2}$ inches across. These minerals are sometimes accompanied by acid plagioclase and more rarely by turbid orthoclase. Calcite, chlorite and serpentine are generally present, and in one instance small patches of purplish fluorspar were noted.

That they are of the nature of segregation veins is proved by the facts that they are identical in composition with some of the irregular segregations found completely enclosed in the Merensky Horizon, and that they are sometimes actually connected with such segregations.

They evidently represent magmatic residua rich in volatile constituents, left over in the crystallisation of the Merensky Horizon, which consolidated in shrinkage cracks. Like the segregations they are products of the pneumatolytic stage of the crystallisation of the Merensky Horizon. They carry, as a rule, only traces of platinum but sometimes fair amounts of sulphides. The precise nature of these sulphides has not as yet been investigated.

Roof and Floor Relations.

It has already been indicated that over the entire distance over which the Merensky "Reef" has been traced in the Rustenburg, Lydenburg, Pietersburg, Pretoria and Potgietersrust districts it is overlain and underlain by light-coloured norites or anorthosites. The constant presence of these rocks proves, as will be pointed out in the sequel, that there is a complementary genetic relation between them and the dark-coloured pyroxenitic platinum-bearing rocks. In places the

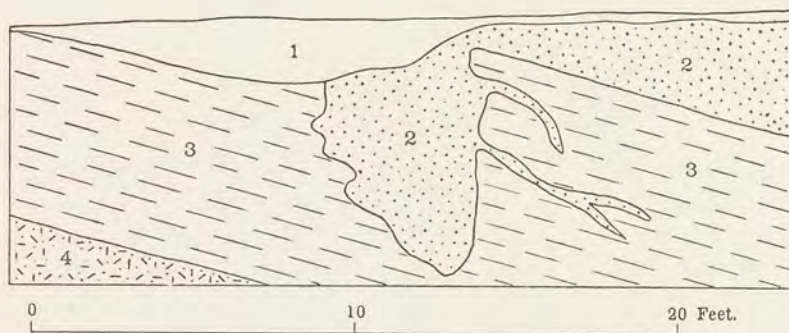


FIG. 15.—Section exposed on South Face of No. 1 Working, Forest Hill, No. 342, Lydenburg District. Shows intrusion of hanging-wall spotted-anorthosite, in Merensky Platinum Horizon.

- | | |
|-------------------------|--------------------------------------|
| 1. Surface soil. | 3. Merensky "Reef." |
| 2. Spotted anorthosite. | 4. Fine-grained anorthositic norite. |

rocks constituting the horizon are sharply defined from the hanging and footwall norite or anorthosite. In other places there is a gradual transition from the platinum-bearer to the hanging-wall norite. The contact between the horizon and the rocks under- and overlying it is, as a rule, smooth and regular. In places, however, as a consequence of movement during consolidation, the ore body is seen to send irregular tongues and apophyses into the footwall norite or anorthosite, and the hanging-wall norite is seen to send similar apophyses downward into the ore body (Fig. 15). In the No. 2 working on Forest Hill, No. 342, Lydenburg district, big inclusions of light-coloured anorthositic norite torn or floated off the footwall are enclosed in the lower part of the ore body. They are



1. Apophyses of hanging-wall spotted anorthosite in platinum-bearing Merensky "Reef," No. 1 Working, Forest Hill, No. 342, Lydenburg district.



2. Shows abrupt downward bulge of dark pyroxenitic norite, constituting lower part of Merensky Horizon, into spotted anorthositic footwall norite (white), across the pseudo-stratification of which it is seen to cut. Exposure in working on Helena, No. 220, Lydenburg district.



conspicuous on account of their lighter colour, and also because the pseudostratification planes in the inclusions are inclined at 35 degrees to the west, whereas the inclination of the ore body is only about 15 degrees. In one of the workings on Helena, No. 220, Lydenburg district, the dark pyroxenitic norite constituting the basal part of the horizon is seen to bulge abruptly downward into the spotted anorthositic footwall norite, cutting across the pseudostratification of that rock (Plate XV.2). The phenomena here briefly described are of great interest in proving what geologists had long surmised, namely, that the crystallisation of the rocks of the norite zone proceeded regularly from below upward, and that the consolidation of the anorthositic norite or spotted anorthosite forming the footwall of the platinum horizon was complete before that of the ore body itself began; further, that the consolidation of the ore body as a whole had been completed when the hanging-wall anorthosite was still in a molten or plastic condition. This does not, of course, preclude the possibility of the pegmatitic facies of the ore having retained their fluidity after the hanging-wall anorthosite had crystallised. Indeed, in the Main Incline on Maandagshoek, small wedge-like apophyses of pegmatitic pyroxenite are seen at one point to penetrate a few inches into the hanging-wall norite. No instances were noted, however, in all the hundreds of sections which the writer has examined, of the more normal Merensky "Reef" or felspathic pyroxenite or harzburgite sending off apophyses into the hanging wall. There is thus no warrant for the view put forward by E. Reuning (59) that the Merensky Horizon is of the nature of an intrusive sill. Sections such as that shown in Fig. 15, indeed, are sufficient to negative that view. Reuning quotes as an additional argument in support of his contention that one of the irregular bodies of platinum-bearing rock enclosed in the footwall anorthosites on Helena, No. 220, sends veins and branches into the overlying anorthosite. But this particular body of rock, which is known to the writer, does not consist of Merensky "Reef" but of coarse pyroxenite which is definitely intrusive in the footwall anorthosite. It belongs to the same category as the dunitic and pyroxenitic intrusions cutting the Merensky Horizon in the Rustenburg district.

**Petrography of the Rocks Overlying and Underlying
the Merensky Horizon.**

The rock immediately underlying the horizon is, as already indicated, variable in character. Over considerable sectors of the Rustenburg and Lydenburg fields it is light-coloured spotted norite. This consists of irregular grains and patches of pyroxene—clino-bronzite with subordinate diallage—sparsely but uniformly scattered through the ground of white or bluish-grey grains of labradorite-bytownite.

The maximum diameter of grain is about 3 mm. Thin sections prove that the bronzite occurs in anhedral moulded on the felspar where they are holohedral or subhedral. The diallage is in irregular ragged grains and is moulded on the bronzite. Subordinate amounts of chromite and magnetite are sometimes present. Below water-level the rock carries minute sulphide grains. These mostly occur in clusters and bunches and are sometimes segregated in small stringers. Individual grains range up to 1 mm. in diameter.

No analysis of this footwall "spotted," as it is generally termed, is at present available, but it is so similar in appearance to the spotted anorthositic norite forming the hanging wall of the horizon in certain areas, of which an analysis is given on page 125, that its composition is probably accurately represented by that analysis.

Mottled anorthosite, with big shadowy poikilitic pseudophenocrysts of clino-bronzite in a white or bluish-grey feldspathic base, forms the footwall in some areas as, for instance, on Elandsfontein, No. 820, in the Rustenburg district, and Forest Hill, No. 220, in the Lydenburg district.

Locally, as on Schildpadnest, No. 233, in the Rustenburg district, and on Dwarsrivier, No. 56, in the Lydenburg district, pure white marble-like labradorite-bytownite anorthosite forms the footwall. But this is gradually found within a short distance to grade into mottled anorthosite. In the central sector of the Potgietersrust fields the footwall of the platinum-bearer, where this does not rest directly on altered dolomite, is everywhere formed by a sheet of rather fine-grained greyish spotted anorthositic norite composed of labradorite-bytownite, bronzite and diallage.

The chemical analysis of this rock is given in column I. of the following table:—

Table of Analyses.

	I.	II.
SiO ₂	49.70	48.85
TiO ₂	0.28	0.10
Al ₂ O ₃	23.20	26.45
Cr ₂ O ₃	0.07	...
Fe ₂ O ₃	0.92	0.45
FeO	4.02	2.15
MnO	0.09	...
MgO	5.46	4.25
CaO	12.32	14.05
K ₂ O	0.89	trace
Na ₂ O	2.43	2.10
P ₂ O ₅	0.08	0.05
CO ₂	0.20	trace
H ₂ O+	0.68	0.15
H ₂ O-	0.10	0.10
Ni	0.01	...
S	0.04	...
Cu	0.01	...
	<u>100.50</u>	<u>100.70</u>

- I. Fine-grained footwall norite. Zwartfontein, No. 121, Northern Sector, Potgietersrust Fields. Quoted from Reuning, E. Anal., L. Möser.
 II. Spotted anorthositic hanging-wall norite. Forest Hill, No. 342 Anal., H. G. Weall.

The rocks overlying the platinum horizon are also variable in character, but not to the same extent as those forming the footwall. As a rule the hanging wall is formed of a rather light-coloured spotted norite into which, as previously stated, the Merensky "Reef" often merges by imperceptible gradations.

It is composed of grains and patches of greenish-brown bronzite and diallage scattered through a white or bluish-grey ground of felspar grains and crystals. The relative amounts of plagioclase and pyroxene vary considerably. With a decrease of the proportion of plagioclase the rock becomes a spotted anorthositic norite or anorthosite.

Such spotted anorthositic norite forms the hanging wall of the horizon over considerable areas in the central part of the Lydenburg district, as for example, on Maandagshoek, No. 148, and Forest Hill, No. 342. The chemical analysis of a specimen of spotted anorthositic norite from Forest Hill is given in

column II. in the Table of Analyses on page 125. In the Lydenburg and Rustenburg districts the hanging wall "spotted" is, as already indicated, generally overlain by a layer of mottled anorthosite. This consists of big poikilitic anhedral of clino-bronzite ranging up to 6 cm. across set in a base of interlocking white or bluish-grey felspar grains. The big bronzite individuals, through being crowded with felspar chadacrysts, have curious, indefinite outlines. They are accompanied by grains of diallage. This mottled anorthosite is of varying thickness. It is generally overlain by a sheet of spotted anorthositic norite, but sometimes directly by the "Bastard Reef." The latter is developed in the Rustenburg and Lydenburg districts, but appears to be absent on the Potgietersrust fields. It normally lies about 30 feet above the Merensky Horizon and is from 8 to 22 feet in thickness. It consists, as a rule, of a sheet of pseudoporphyrific diallage-norite resembling the normal Merensky "Reef." In the southern part of the Rustenburg district it is finer grained than the typical Merensky "Reef," with smaller phenocrysts of green diallage. In the northern part of the same district it is more pyroxenitic, and the lower part of the "reef" is actually a medium-grained feldspathic pyroxenite.

On Schildpadnest, No. 233, in the northern part of the Rustenburg district, the footwall of the "Bastard Reef" is formed of a layer of almost pure anorthosite (Fig. 19). The "Bastard Reef" here in places carries small amounts of platinum. Overlying it is a sheet of spotted norite, and this is generally overlain by a considerable thickness of mottled anorthosite with big bronzite pseudo-phenocrysts.

Throughout the Rustenburg fields there is present in this zone of mottled anorthosite a very resistant layer weathering in big rounded boulders and hummocks or in picturesque rugged kopjes. It lies about 1000 feet horizontally above the platinum horizon in the southern part of the fields, and about 400 feet above it, again horizontally, in the northern part. This particular layer, with its prominent outcrops, proved an invaluable horizon marker when Dr Merensky and his associates were tracing the platinum horizon beneath the vast "black turf" flats of this part of the Bushveld Complex.

It should be stated that the big pseudo-phenocrysts of bronzite, which are up to 5 cm. across, are less resistant than



1. Characteristic exposure of mottled anorthosite overlying "Bastard Reef" on Doornspruit, No. 878. The mottled anorthosite proved an invaluable horizon marker when the Merensky Horizon was being traced beneath the "Black Turf" flats of the Rustenburg district.



2. Shows the contact between dark platinum-bearing feldspathic harzburgite, constituting lower part of the Merensky Platinum Horizon, and underlying footwall anorthositic norite; exposure on wall of Main Western Incline of Kroondal-Klipfontein Mine. The feldspathic harzburgite is seen to be traversed by irregular veins of dense magnesite.



the felspar base in which they are embedded. They, in consequence, weather out more rapidly, and exposed surfaces of the rock generally present a curious pitted appearance (Plate XVI.1).

In the central sector of the Potgietersrust platinum fields, on the farms Sandsloot, Vaalkop and Zwartfontein, the felspathic pyroxenite and Merensky "Reef" constituting the platinum horizon are usually overlain by a fairly thick sheet of coarse-grained anorthositic diallage-norite exhibiting a peculiar poikilitic texture. The rock weathers in big rounded boulders (Plate XVI.1). It consists of big dark anhedra of diallage and bronzite riddled with chadocrysts of felspar scattered through a grey or greenish-grey felspar base. The rock differs from the normal mottled anorthosite, above described, in that diallage here preponderates among the pseudo-phenocrysts, and that the felspar chadocrysts which it encloses are bigger than in the mottled anorthosites of the Rustenburg and Lydenburg districts. It merges upward into a normal mottled norite which is itself succeeded by a dark anorthositic norite. Locally it is also underlain by coarse mottled norite.

CHAPTER XI

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

The Merensky Horizon in the Rustenburg and Pretoria Districts.

Rustenburg District.—The Merensky Horizon, as already stated, attains its most important development in the Rustenburg district, where it has been traced at intervals for a distance of 140 miles.

The vast area covered by the Rustenburg platinum fields is throughout one of low relief. Great open flats covered with grass and a species of dwarf acacia, and interspersed with isolated trees and patches of scrub, are broken here and there by rugged kopjes and conspicuous conical hills. Examples are Vaalkop on the farm of that name, Kookfontein Hill and the perfect cones to the north-east of the Pilandsberg (Plate VI.1). South of Bleskop Station a succession of long low ridges marks the position of a great foyaite dyke.

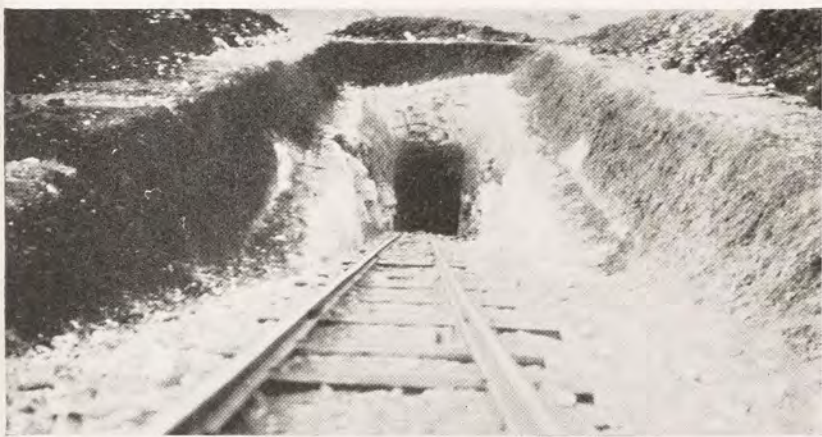
Outcrops, speaking generally, are few and far between, an almost continuous sheet of Black Turf¹ soil covering like a great pall the portion of the norite zone containing the Merensky Horizon (Plate XVII.1).

The fields are rather poorly off as to water. They are traversed in their southern portion by several perennial streams, but, as the mines are debarred by the irrigation laws from taking water from these streams, recourse has had to be had to dams and boreholes.

¹ This is a heavy sticky clayey soil of greyish-black to blue-black colour, very rich in colloids, that is often found in Central South Africa on poorly drained areas underlain by basic igneous rocks. It swells very considerably when wetted and on drying develops gaping shrinkage cracks divided into polygonal columns. Contrary to popular belief it is not very rich in humus, its colour being apparently due to a colloidal iron compound.



1. Portal of No. 2 Incline on Merensky Horizon, Schildpadnest, No. 233, Rustenburg district. The "Black Turf" soil covering the platinum horizon is seen in the foreground, and a prominent outcrop of mottled anorthosite in the background.



2. Portal of No. 7 Incline on Merensky Horizon, Waterval, No. 1023, Rustenburg district.



The most regular and continuous stretch of the Merensky Horizon lies south-east and east of the town of Rustenburg (see Plate XXXVII.), and it is here that one or probably two important mines will be producing in the near future. The stretch or sector in question can be traced from the southern part of the Rustenburg Town Lands first in a south-easterly and then in a general east and west direction across the farms Waterval, No. 1023, Kroondal, No. 177, Klipfontein, No. 538, to the middle of Brakspruit, No. 393. On the boundary between Klipfontein and Brakspruit the outcrop has been displaced southward, on the latter farm, for some 200 feet along a fault occupied by a dyke of foyaite-porphyry. About two and a half miles to the east on the same farm there is a similar southward displacement along a parallel foyaite dyke. Beyond the middle of Brakspruit the horizon is less regularly developed, though a very promising stretch is said to have been opened up in the central portion of the adjoining farm Roodekopjes, No. 171. On Middelkraal, No. 538, which adjoins Roodekopjes on the east, it is much broken up by dunite and pyroxenite intrusions, and at one point has been faulted south-eastward for a fairly considerable distance. It is also much broken on Turffontein, No. 356, and Kafferskraal, No. 597, and difficult to follow. The horizon has, however, been definitely located some eleven miles to the east on the farm Elandsfontein, No. 374, in the Pretoria district. To this occurrence further reference will be made.

North of Rustenburg the horizon has been traced in a general north-westerly direction as far as the north-western corner of Boschkopje, No. 685, a distance measured along the strike of some twenty miles. This sector is also much broken and disturbed by dunite intrusions, and the only apparently workable stretch is on Boschkopje.

Beyond Boschkopje it comes within the aureole of disturbance that encircles the Pilandsberg. Only short isolated stretches have been picked up at considerable intervals, one such on Vogelstruisnek, No. 602, west of the Pilandsberg, another on Zandspruit, No. 181, and yet another on Witkliefontein, No. 20, both north-west of the Berg. From Witkliefontein the rocks from the associated horizon have been traced through Wilgespruit, No. 631, and adjacent farms, but the horizon itself is not definitely picked up again until Turfbult, No. 989,

is reached. This farm lies 11 miles north-north-west of the northern edge of the Pilandsberg. On it and the adjacent farm Swartklip, No. 988, there has been opened up a very important sector of the horizon which, on Swartklip, is as regular and carries as high values as anywhere in the Rustenburg district. Near the eastern boundary of Swartklip there is a considerable break, the horizon being next met with in the northern part of Elandsfontein, No. 820, about 10 miles to the north-east. From here it can be traced fairly continuously in a north-easterly direction through the farms Schildpadnest, No. 233, Swartkop, No. 355, Middellaagte, No. 997, and Elandskuil, No. 149, a distance measured along the strike of about $10\frac{1}{2}$ miles. This stretch contains two very important sectors, one on Elandsfontein, No. 820, and the other on Schildpadnest, No. 233. Here again the values are equal to those found anywhere in the Rustenburg district.

Facies of the Platinum Horizon.—It has already been pointed out that in the Rustenburg district the horizon is everywhere composite in character and that the main platinum carriers are a layer of coarse felspathic harzburgite and a thin chrome band that either over- or underlies it (Figs. 16, 17, 18). Where the layer of felspathic harzburgite is thin the whole of it is platinum-bearing; where thick, the platinum metals are concentrated in the portion adjacent to the Chrome Band. In some localities the Chrome Band occurs at the base of the horizon with coarse felspathic harzburgite above it. In others, while still occurring in the lower portion of the horizon, the Chrome Band is underlain by felspathic harzburgite. In yet others it occurs immediately below the Merensky "Reef" at the top of the main carrying portion of the horizon, being again underlain by felspathic harzburgite.

Three distinct facies of the Merensky Horizon may thus be distinguished on the Rustenburg fields according as the Chrome Band occurs at the top or bottom of the workable portion of the horizon, and according as the layer of coarse felspathic harzburgite occurs above or below the Chrome Band. They are:—

- (1) The *Kroondal* facies as developed to the south-east and east of Rustenburg. In this the Chrome Band occurs at the base of the horizon and the coarse felspathic harzburgite above it.

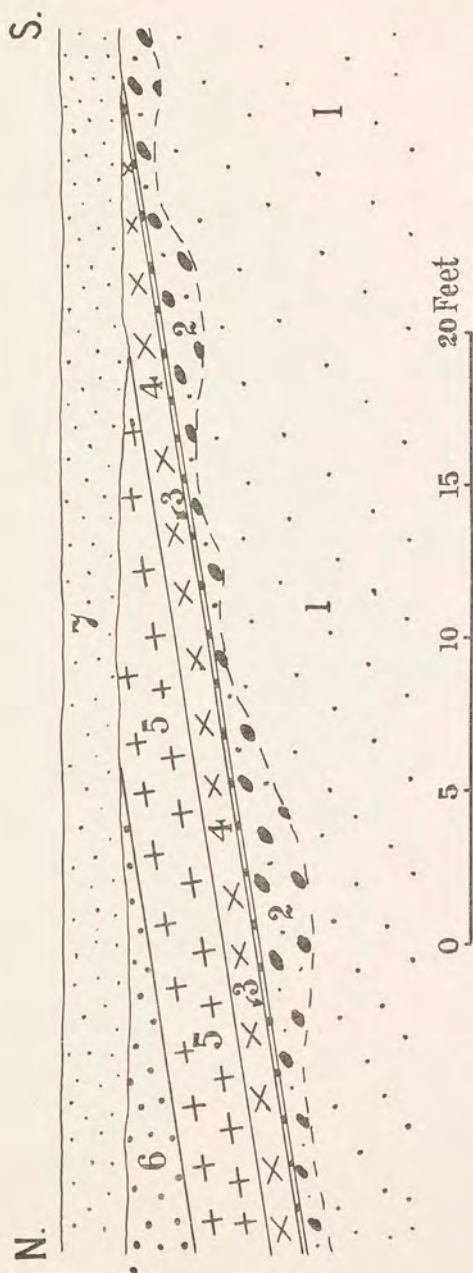


FIG. 16.—Detailed Section across Merensky Platinum Horizon in the original Main Working on Kroondal, No. 177, South-East of Rustenburg.

1. Spotted Anorthositic Norite.
2. Iron-stained Platinum-bearing Spotted Anorthositic Norite.
3. Chrome Band (rich in Platinum).
4. Coarse Pegmatic Felspathic Pyroxenite (lower 4 inches rich in Platinum, upper 8 inches fairly rich in Platinum).
5. Merensky Reef (pseudoporphyritic pyroxenite Diallage-norite) sparingly Platinum-bearing.
6. Spotted Norite.
7. "Black Turf" Soil.

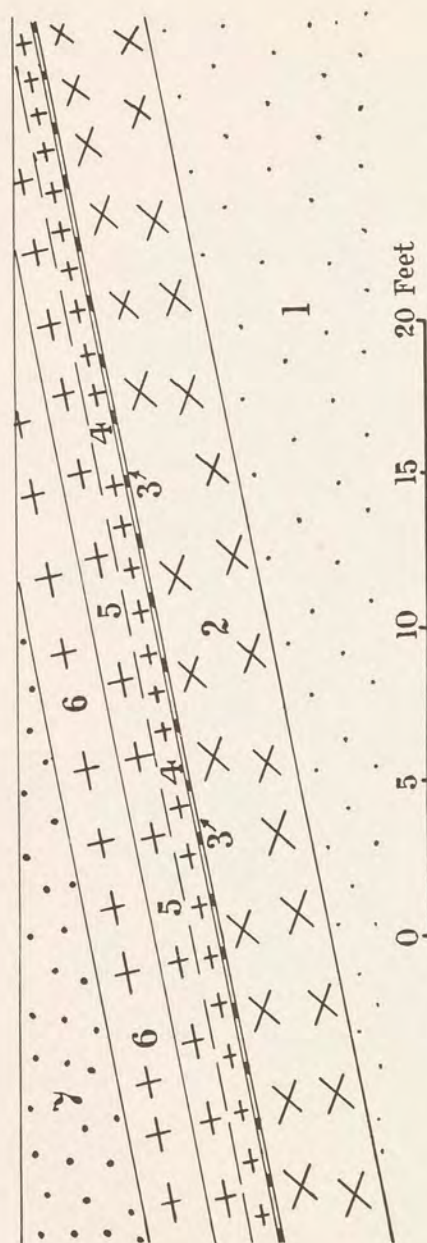


FIG. 17.—Detailed Section across Merensky Platinum Horizon in Main Incline on Doornspruit, No. 878, North-West of Rustenburg.

1. Spotted Anorthositic Norite.
2. Coarse Pegmatitic Felspathic Pyroxenite (upper 24 inches Platinum-bearing).
3. Chrome Band (Platinum-bearing).
4. Rather Fine-grained Merensky Reef (Platinum-bearing).
5. Coarse-grained Merensky Reef (sparingly Platinum-bearing).
6. Coarse-grained Hanging-Wall Reef (Diallage-norite with isolated pseudo-phenocrysts of Diallage).
7. Spotted Norite.

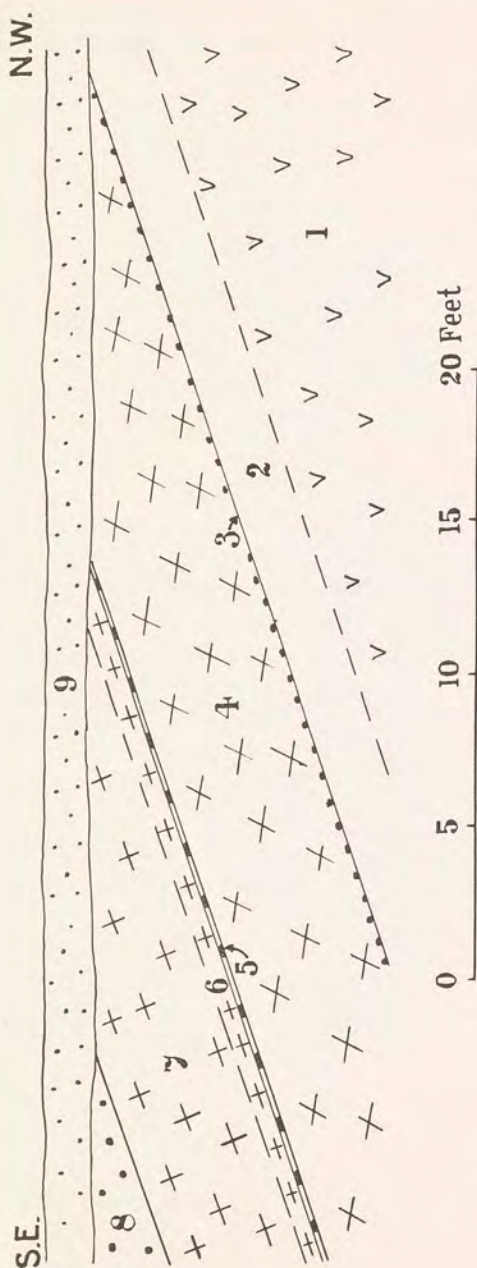


FIG. 18.—Detailed Section across Merensky Platinum Horizon in No. 2 Incline, Schildpadnest, No. 233, Rustenburg District.

1. Mottled Anorthosite.
2. Anorthosite in part slightly mottled.
3. Footwall Chrome Band.
4. Coarse Pegmatitic Felspathic Pyroxenite (uppermost 2 feet fairly rich in Platinum).
5. Main Chrome Band (rich in Platinum).
6. "Merensky Reef" (medium-grained copper-stained pseudoporphyrific pyroxenitic Diallage-norite, Platinum-bearing).
7. "Hanging-Wall Reef" (fairly coarse-grained pseudoporphyrific Diallage-norite).
8. Spotted Norite.
9. "Black Turf" Soil.

- (2) The *Doornspruit* facies as developed on the farm of that name to the north-west of Rustenburg and other localities to be mentioned later. Here the coarse felspathic harzburgite occurs at the base of the horizon with the Chrome Band above it.
- (3) The *Swartklip* facies as developed north-north-west of the Pilandsberg. Here the Chrome Band occurs at the top of the workable portion of the horizon and there is, as a rule, a considerable thickness of coarse felspathic harzburgite below it; beneath this there is generally another thin chrome band resting on an anorthositic footwall.

The individual facies may next be considered in greater detail.

I. The Kroondal Facies.—This is developed on part of the Rustenburg Town Lands and in the very important sector extending from the Town Lands to the farm Roodekopjes, No. 171. Most work has actually been done on the farms Kroondal, No. 177, and Klipfontein, No. 538, where the *Potgietersrust Platinums, Ltd.*, are at present erecting a treatment plant with a capacity of 6000 tons per month. An 18,000-ft. sector of the horizon has here been opened up by means of vertical and incline shafts to a depth, measured on the incline, of 2000 feet, which corresponds with a vertical depth of 300 feet. The strike is roughly east and west and the dip is to the north at from 9 to 10 degrees. The oxidised zone extends to an average depth of 700 feet measured on the incline, so that the horizon here may be well studied in both the oxidised and sulphide zones. It is of extraordinary regularity both as to constitution and platinum content. The horizon ranges in thickness from 3 feet to 5 feet 8 inches. Sections across it (see also Fig. 16) show, in descending order:—

- (1) Hanging-wall spotted norite.
- (2) From 18 inches to 3 feet of Merensky "Reef," that is, pseudoporphyrific pyroxenitic diallage-norite, the upper 12 inches generally coarser in grain and less mafic than the lower 12 inches to 2 feet.
- (3) A layer of coarse felspathic harzburgite from 12 inches to 24 inches in thickness.

- (4) A thin chromite-rich layer averaging $\frac{3}{4}$ inch in thickness and known as the Chrome Band.
- (5) Footwall spotted anorthositic norite. In the oxidised zone the portion of the footwall underlying the Chrome Band is, to a distance of up to 2 feet 6 inches from it, mottled and streaked with secondary iron oxide. This iron-stained anorthositic spotted norite carries, as we shall learn, notable amounts of secondarily deposited platinum metals.

In some parts of the mine there is a second chrome band in the coarse felspathic pyroxenite from 12 to 15 inches above the footwall chrome band. Thus, at the portal of the Central Incline on Klipfontein, there is exposed the section given below :

	Inches
Norite	...
Spotted hanging-wall norite	...
Merensky "Reef"	33
Coarse felspathic harzburgite	6
Upper Chrome Band	$\frac{1}{2}$
Coarse felspathic harzburgite	14
Main Chrome Band	1
Iron-stained platinum-bearing spotted anorthositic footwall norite	15
Spotted anorthositic footwall norite	...

Lenticular intercalations of medium-grained spotted norite and anorthosite are sometimes found in the Merensky "Reef." One such was noted at the portal of the West Incline on Kroondal where one sees, in downward succession :

	Inches
Spotted hanging-wall norite	...
Merensky "Reef"	14
Medium-grained spotted norite and anorthosite	4
Merensky "Reef"	14
Coarse felspathic harzburgite	16
Chrome Band	$\frac{3}{4}$
Iron-stained platinum-bearing spotted anorthositic footwall norite	6 to 18

The petrography of the platinum-bearing rocks has already been dealt with in the general description of the Merensky Horizon. Brief reference need here be made only to the footwall Chrome Band. In this particular sector this is a black

and white speckled rock composed of small crystals and grains of chromite up to 2 mm. across, scattered fairly uniformly through a base composed of big interlocking individuals of labradorite-bytownite, diallage and bronzite. Plagioclase and pyroxene enclose the chromite poikilitically, the first named mineral predominating.

The several rocks entering into the constitution of the platinum horizon assume, on weathering, a curious greenish-yellow or yellowish-green colour, and are often seen to be traversed by veins and seams of secondary dense white magnesite. The Chrome Band, the coarse felspathic harzburgite and the lower part of the Merensky "Reef," moreover, show rusty limonite and green malachite stains. Below the zone of weathering these rocks are, as already pointed out, impregnated with primary sulphides which occur as irregular interstitial grains and patches up to 2.5 mm. across.

Distribution of the Platinum Metals.—The Kroondal-Klipfontein Mine has exceeded all expectations in regard to the uniformity of distribution of the platinum metals in it.

So far, the area on which operations have been concentrated has proved to be 100 per cent. payable. It has been sampled at 5 feet intervals throughout, and the average value for the whole mine works out at about 6 dwts. over a width of 30 inches.

In the sulphide zone the greater part of the platinum metals present is concentrated in the Chrome Band, and the immediately overlying coarse felspathic harzburgite. The lowermost 12 inches of the horizon carry an average of about 13.5 dwts. of platinum metals per short ton. The Chrome Band itself carries an average of about 20 dwts. per ton, and the overlying 4 inches of felspathic harzburgite about 18 dwts., or just about twice as much as the next overlying 18 inches. The Merensky "Reef" is poor in platinum and carries in the sulphide zone an average of 1.7 dwts. of platinum metals per short ton.

As roughly 90 per cent. of the platinum metals present are concentrated in the lowermost 12 or 13 inches, it is proposed to send to the mill only this sector of the horizon, though naturally a considerably greater width will have to be mined.

In the oxidised zone in which the platinum metals are also very uniformly distributed they have, as a result of weathering, been dissipated over a greater width, and here, as will be shown later, the footwall anorthositic norite, which in the sulphide

zone is normally barren, has to a distance of up to 2 feet 6 inches been impregnated with platinum metals leached by surface waters out of the overlying rocks.

The results of the systematic sampling of the ore developed at the Klipfontein-Kroondal Mine during the quarter ended 31st December 1928, were as follows:—

	Footage Developed.	Footage Sampled.	Value; Dwts. Platinum Group Metals per ton.	Width (Inches).
Kroondal—				
Oxidised ore .	267	205	8.1	18.0
Sulphide ore .	1080	1000	11.9	12.6
Klipfontein—				
Oxidised ore .	676	480	7.8	17.3
Sulphide ore .	143	15	11.6	13.0

The Footwall of the Platinum Horizon.—This merits special notice, as it is in some respects the most interesting part of the deposit. It is, as previously stated, formed by a layer of light-coloured anorthositic norite. This rock, below water-level, normally carries only small isolated specks of sulphides and is free from platinum. In places, however, the portion of the layer adjacent to the Chrome Band is interspersed with patches and streaks of primary sulphides, generally associated with small segregations of bronzite, diallage and chromite. Where such is the case, as for example at a depth of 685 feet in the Main Incline on Kroondal, the footwall "spotted" carries high platinum values, in this instance 12 dwts. over a width of 12 inches. The sulphides are identical with those found in the overlying rocks, though chalcopyrite is rather more abundant.

In the oxidised zone the anorthositic norite, as already indicated, is mottled and streaked with reddish-brown secondary limonite to a depth of, up to 2 feet 6 inches below the Chrome Band, and carries notable amounts of platinum.

The patches and streaks of secondary limonite with which the platinum values are associated are found on investigation to be of two kinds, namely,

- (a) Those derived from the oxidation of patches of primary sulphides in the anorthositic norite. They are generally rudely circular in outline, and lie isolated in the rock.

- (b) Those due to the migration into the anorthositic norite from above of secondary iron oxide derived from the weathering of the sulphides originally contained in the overlying rocks. These patches and streaks are in many instances obviously related to joints and cracks in the footwall norite, the greater the degree of jointing and shattering the greater being the distance below the Chrome Band to which they extend.

The platinum metals present in this iron-stained footwall norite must, like the limonite, have been derived mostly from the overlying Merensky Horizon, as it is not possible that more than a small proportion can be indigenous to the anorthositic norite itself which, as we have seen, is normally free from platinum. The platinum metals are for the most part contained in the 3 or 4 inches of anorthositic norite immediately underlying the Chrome Band which carry an average of 4.5 dwts. of platinum metals per short ton. Further reference to these interesting supergene phenomena will be found in Chapter XIV.

Waterval, No. 1023.—On this farm, which adjoins Kroondal on the west, the *Waterval (Rustenburg) Platinum Mining Co., Ltd.*, have done a great deal of exploratory work with excellent results, and are at present contemplating the erection of a treatment plant. The platinum horizon is almost identical in character with that on Kroondal and Klipfontein. The only differences noticed by the writer are that the Chrome Band is here subject to rapid variations in thickness and that the footwall is somewhat wavy, the Band being in consequence in places disposed in sharp little synclines and basins. The strike is north-west to south-east and the average dip is 9 degrees 30 minutes to the north-east.

A section across the horizon in the No. 7 Winze shows:—

	Inches
Spotted hanging-wall norite	...
Coarse-grained hanging-wall facies of Merensky "Reef"	18
Normal Merensky "Reef"	24
Coarse feldspathic harzburgite	15
Chrome Band	$\frac{1}{4}$ to $1\frac{1}{2}$
Iron-stained platinum-bearing spotted footwall anorthositic norite	18
Footwall anorthositic norite	...

The platinum values both in the oxidised zone and in the sulphide zone are much the same as on the two farms already dealt with, the average tenor being about 6 dwts. over a width of 30 inches.

Rustenburg Town Lands.—The development of the horizon on the Rustenburg Town Lands is variable. On the southern portion it is similar to that on Waterval, but the felspathic pyroxenite is generally much thinner and in places it is absent altogether. The platinum values calculated over a stopping width are in consequence generally speaking very low. On the northern portion of the Town Lands the southern facies is also in places developed, while in other places one finds the Doornspruit facies. In the "No. 1" vertical shaft there is a rather abnormal development of the "reef." The Chrome Band, overlain by a thin impersistent seam of coarse felspathic harzburgite, is here underlain by a band of anorthosite two feet thick which itself is underlain by a lower band of coarse felspathic harzburgite resting on a thin chrome band. The section actually is as follows:—

	Inches
Spotted hanging-wall norite . . .	...
Merensky "Reef" . . .	41
Coarse felspathic harzburgite . . .	nil to 2
Chrome Band . . .	$\frac{3}{4}$ to $1\frac{1}{2}$
Faintly spotted anorthosite . . .	21
Coarse felspathic harzburgite . . .	24
Chrome Band (impersistent) . . .	$\frac{1}{4}$
Spotted footwall anorthosite . . .	...

The Kroondal Facies east of Klipfontein, No. 538.

Brakspuit, No. 393.—In the western part of this farm, east of the foyaite dyke already referred to, a promising stretch of the horizon has been opened up by the *Transvaal Consolidated Land and Exploration Company, Limited*.

The development of the horizon is again similar to that on Kroondal and Klipfontein, except that the chromite, instead of being concentrated in a definite footwall band, is in places dispersed through the felspathic harzburgite, forming the lower part of the horizon, in irregular seams and stringers.

Roodekopjes, No. 171, and Middelkraal, No. 358.—West of Brakspuit the horizon, as already stated, has been traced across the farms named, and very promising values are stated to have been obtained on the former.

On Middelkraal the felspathic pyroxenite(?) above the Chrome Band is much thinner than near Rustenburg, and there is a very considerable thickness of Merensky "Reef" above it.

A section in one of the prospecting trenches showed:—

Merensky "Reef" (not fully exposed)	4 feet
Coarse felspathic pyroxenite (?)	$\frac{1}{2}$ to 2 inches
Chrome Band	$\frac{1}{4}$ to 1 inch
Pure or faintly mottled footwall anorthosite	...

II. The Doornspruit Facies.—This facies is unimportant, no considerable workable stretches of the platinum horizon having as yet been discovered in any of the areas where it is present. It is developed on Doornspruit, No. 878, some 15 miles north-west of Rustenburg, on the Rustenburg Town Lands and in the north-western part of Boschkopje, No. 685. A typical section across it (Fig. 17) in the main incline on Doornspruit shows:—

Spotted hanging-wall norite	...
Coarse hanging-wall facies of Merensky "Reef"	2 feet
Coarse-grained Merensky "Reef"	14 inches
Normal medium-grained Merensky "Reef"	10 "
Chrome Band	$\frac{1}{4}$ to $\frac{3}{4}$ inch
Coarse felspathic harzburgite	36 inches
Spotted anorthositic norite	...

On this farm the Chrome Band in places exhibits a peculiar development. It shows oval crystals of dull greyish-green bronzite up to 2 cm. long, and equally long but narrower individuals of greenish-grey diallage, both enclosing numerous chadacrysts of chromite scattered through a matrix of interlocking chromite crystals. One of the big pseudo-phenocrysts was found to consist of a core of bronzite encased in an outer shell of diallage, the two minerals having the c -axis in common. In another prospecting trench on the farm the Chrome Band is in the form of a seam up to 6 mm. thick composed of interlocking chromite crystals up to 3 mm. across.

Rustenburg Town Lands.—The Doornspruit facies is, as stated above, developed in certain parts of the Rustenburg Town Lands. Thus, the No. 9 Borehole showed the following section:—

	Inches
Spotted hanging-wall norite	...
Coarse hanging-wall facies of Merensky "Reef"	12
Normal Merensky "Reef"	18
Chrome Band	$\frac{1}{2}$
Coarse felspathic pyroxenite	4
Spotted anorthosite footwall norite	...

Boschkopke, No. 685.—On this farm, belonging to the *Transvaal Consolidated Land and Exploration Company, Limited*, a considerable amount of exploratory work has been done on the Merensky Horizon. In its south-eastern portion the southern facies of the horizon is developed, and in the north-western portion the Doornspruit facies.

The most promising results have been obtained on the south-eastern portion of the farm where the horizon has been explored by means of trenches, cuttings and an incline shaft which has a depth of 605 feet. The sulphide zone was entered at 405 feet on the incline, equivalent to a vertical depth of 100 feet. The shaft has been systematically sampled. The average value for 405 feet sunk in oxidised and semi-oxidised ore was 4.8 dwts. of platinum metals over 36 inches. The average value for the remaining 120 feet sunk in sulphide ore was 6.1 dwts. over 36 inches.

The Horizon West and North-West of the Pilandsberg.—Isolated short stretches of the Merensky Horizon have, as previously noted, been located west and north-west of the Pilandsberg. None of them appear to have any economic significance. That opened up in the northern part of Vogelstruisnek, No. 602, shows a development of the southern facies, the Chrome Band overlain by a thin seam of felspathic pyroxenite resting on an anorthosite footwall.

III. The Swartklip Facies.—This is developed in two areas, namely, on the farms Turfbult, No. 989, and Swartklip, No. 988, between 11 and 16 miles north-north-west of the Pilandsberg, and on Elandsfontein, No. 820, and adjoining farms situated some distance to the north-east.

Turfbult and Swartklip.—On these farms the horizon has been opened up over a distance of some 18,000 feet along the strike and to a depth, measured on the dip, of 450 feet by the *Platinum Exploration Company, Limited*. The strike is north-east to south-west, and the dip 25 degrees to the south-east. (See *Frontispiece*, Plate I.).

A feature of the horizon here is the thickness of coarse harzburgite or felspathic harzburgite underlying the chrome band which, as previously stated, is at or near the top of the workable portion of the horizon. The thickness was found to be nearly 23 feet in the only working where a complete section across these rocks is exposed. The harzburgites are also

characterised by being unusually coarse-grained, and show crystals of diallage and bronzite up to 6 inches across. The two minerals are usually in poikilitic intergrowth, the latter enclosing the former.

The chrome band, which in this area ranges from $\frac{1}{2}$ inch to 6 inches in thickness, and is rich in platinum, is usually made up of an aggregate of interlocking grains and crystals of lustrous black chromite up to 2.5 mm. across, with practically no interstitial silicates. In places, however, bronzite and diallage are present, and the rock then exhibits the characteristic pseudoporphyratic poikilitic texture of the Bushveld chromite with pseudo-phenocrysts of these minerals up to 1 inch in length.

The following are typical sections across the horizon:—

Swartklip; No. 7 Incline:—

Spotted hanging-wall norite.

Coarse hanging-wall facies of the Merensky "Reef," thickness unknown.

Normal Merensky "Reef," at least 10 inches (lower 3 inches platinum-bearing).

Chrome Band, $\frac{3}{4}$ inch (platinum-bearing).

Coarse feldspathic harzburgite, interspersed in its lower portion with patches of Merensky "Reef" (uppermost 18 inches platinum-bearing), 23 feet.

Footwall Chrome Band, $\frac{1}{2}$ inch.

Faintly mottled footwall anorthosite.

Turfbutt; No. 3 Incline:—

Hanging-wall facies of coarse Merensky "Reef," thickness unknown.

Normal Merensky "Reef," at least 24 inches (lowermost 3 inches platinum-bearing).

Very coarse harzburgite partially exposed, 6 feet (uppermost 18 inches platinum-bearing).

Near the entrance to this incline there is a second thin chrome band 12 inches above the main Chrome Band, and separated from it by a layer of pyroxenitic Merensky "Reef." The two chrome bands coalesce at about 30 feet from the surface.

Platinum Values.—On both these farms the platinum metals are concentrated in the Chrome Band and the feldspathic harzburgite or harzburgite immediately underlying it. The values are most uniform on Swartklip, though a promising sector has also been proved in the north-eastern part of

Turfbult. On Swartklip there has been proved a 13,000-ft. stretch of the horizon which, as regards platinum values, is equal to anything hitherto opened up in the Bushveld Complex. It is being systematically opened up by means of three incline shafts known as Nos. 4, 7 and 9. These have attained depths of 390, 310 and 500 feet respectively. The sulphide zone is entered at a depth of 270 feet measured on the incline. Tunnels are being driven east and west along the strike in the sulphide zone at the 320-ft. level, and it is proposed to put down winzes at intervals of 500 feet so that the horizon will be divided into rectangular blocks measuring 500 feet by 320 feet. The incline shafts and drives and the shallower trenches and inclines on the property have been systematically sampled at 5 feet intervals. The results are summarised below. It should be stated that in arriving at the average value "reduced," all values over 10 dwts. have been reduced to that figure.

Working.	Depth.	Number of Samples taken.	Average Value (Reduced).	
			Over 36 In.	Over 30 In.
No. 1 Incline . . .	25 feet	7	4.8 dwts.	5.73 dwts.
" 2 " . . .	50 "	10	6.2 "	6.47 "
" 3 " . . .	30 "	7	5.8 "	6.64 "
" 4 " . . .	365 "	94	6.04 "	7.01 "
" 6 " . . .	35 "	4	9.15 "	9.74 "
" 7 " . . .	230 "	67	5.54 "	6.51 "
" 8 " . . .	20 "	5	7.4 "	8.52 "
" 9 " . . .	450 "	153	6.22 "	7.09 "
" 1 West Drive . .	90 " (length)	36	5.63 "	6.61 "
" 1 East Drive . .	95 " (")	38	5.98 "	6.89 "
" 10 Incline . . .	25 "	5	8.47 "	8.97 "
" 11 " . . .	55 "	11	7.34 "	8.0 "
" 13 " . . .	10 "	3	6.2 "	6.74 "
" 14 Trench . . .	...	1	3.3 "	4.06 "
" 15 Incline . . .	15 "	3	0.7 "	0.84 "
" 16 Trench . . .	...	1	8.9 "	10.0 "

The average of all samples taken to date works out at—

5.78 dwts. (platinum metals) over 36 inches, or
6.95 " " 30 "

The platinum values are, as already stated, concentrated in the Chrome Band and the felspathic harzburgite immediately underlying it. This is especially the case in the sulphide zone. It should be stated that in the sulphide zone the horizon is sampled in two sectors, namely, in the upper 12-inch and the

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lower 18-inch sectors. The upper 12-inch sector includes the Chrome Band, 3 inches of the overlying Merensky "Reef" and an average of 8 inches of the underlying felspathic harzburgite. The lower sector includes the 18 inches of coarse felspathic pyroxenite underlying the upper sector.

The following figures showing the results of the sampling of certain of the inclines and drives give an idea of the relative amounts of the platinum metals present in these two sectors.

Sector Sampled.	Number of Samples.	Average Platinum Metals Content of Upper 12 in. (dwts. per short ton).	Average Platinum Metals Content of Lower 18 in. (dwts. per short ton).
No. 9 Incline (between 430 and 450 feet)	5	19.8	1.9
No. 1 West Drive off No. 9 Incline (between 70 and 90 feet)	5	18.9	2.6
No. 1 East Drive off No. 9 Incline (between 75 and 90 feet)	5	26.1	0.4
No. 7 Incline (between 190 and 230 feet)	9	16.2	0.37

The Chrome Band is not itself, as was at one time supposed, abnormally rich in platinum. Thus a sample over an average thickness of $1\frac{1}{2}$ inches taken in sulphide ore at 280 feet on the east face of the No. 4 Incline returned 16.7 dwts. of platinum and 4.8 dwts. of palladium per ton of 2000 lb. The percentages of platinum and palladium calculated from this assay are as follows:—

Platinum	77.7 per cent.
Palladium	22.3 „

These percentages are probably fairly representative of the horizon as a whole.

In the north-eastern part of *Turfbul* the horizon has been opened up by means of three inclines and tunnels. These, too, have been systematically sampled and the results of the sampling are given below.

The Platinum Exploration Company, Limited, contemplate the erection of a treatment plant on Swartklip in the near future.

The Elandsfontein-Elandskuil Sector.—This has a length of nearly 10 miles. The most important portion of the sector is on the farm Schildpadnest, where there was opened up by the Steelpoort Platinum Syndicate a remarkably promising stretch of the horizon 6300 feet in length. This has since been

PLATE XVIII



1. Portal of No. 4 Incline on Merensky Horizon, Swartklip, No. 989, Rustenburg district.



2. Shows one of the earliest prospecting pits on the Merensky Horizon. View on Driekop, No. 170, Lydenburg district. Norite hills in the middle distance; Lulu Mountains in the background.



acquired by the *Potgietersrust Platinums, Limited*. The strike of the horizon here is north-east to south-west and the dip to the south-east at from 18 to 24 degrees. The horizon shows much the same development as on Swartklip and Turfbult, except that the felspathic harzburgite underlying the Chrome Band is here much thinner and also less coarse in grain. A typical section across the horizon in the upper part of the No. 2 Incline (Fig. 18) shows:—

Spotted norite	...
Hanging facies of Merensky "Reef"	4 feet 4 inches
Merensky "Reef" exhibiting spheroidal weathering	5 inches
Chrome Band	$\frac{3}{4}$ inch
Coarse felspathic harzburgite	4 feet 10 inches
Footwall Chrome Band	$\frac{1}{4}$ inch
Anorthosite in part faintly mottled	2 feet
Mottled anorthosite	...

In the sulphide zone, which is entered at an average vertical depth of 85 feet, the platinum metals are again concentrated in the Chrome Band and the immediately underlying felspathic harzburgite. In the oxidised zone the platinum has, as in the Rustenburg area, been dissipated and the Merensky "Reef" also carries good values.

The horizon has been systematically explored to a depth of 350 feet, measured on the incline, by means of incline shafts and drives, and has also been tested at depth by means of boreholes. One of the boreholes cut it at a depth of 333 feet, this being the greatest vertical depth below the surface at which it has so far been intersected anywhere in the Transvaal. It is gratifying to be able to record that the horizon, where cut, proved to be as rich as anywhere near the surface. The core actually averaged 7.3 dwts. over 30 inches. Another borehole intersected the horizon at 300 feet. Here the core is richer, assaying 11.4 dwts. over 30 inches. The distribution of the platinum metals is also very similar to that on Swartklip and Turfbult. In the sulphide zone, which is entered at an average vertical depth of some 85 feet, the platinum metals are practically concentrated in the Chrome Band and the immediately underlying felspathic harzburgite.

The Chrome Band, which ranges from 0.5 to 3.5 inches in thickness, carries from 15 to 59.2 dwts. of platinum metals per ton. The Merensky "Reef" overlying it is practically

barren of platinum metals. The 18 inches of felspathic harzburgite immediately underlying the Chrome Band carries up to 42.5 dwts. of platinum metals per ton. The 18 inches below this, while carrying occasionally good values, are not workable. Thus in the vertical shaft which intersected the horizon in the sulphide zone at 95 feet this particular section carried an average of only 0.2 dwt. of platinum per ton. The same applies to the next underlying 18 inches.

The footwall Chrome Band carries values here and there, but on the whole is poor in platinum. The workable values are thus again concentrated in a width of some 18 inches.

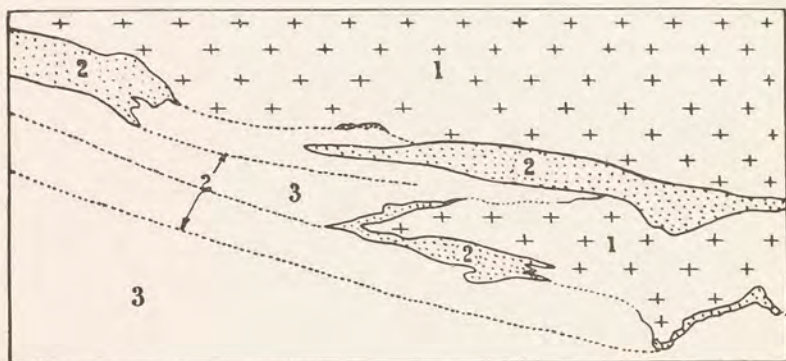


FIG. 19.—Section illustrating relation between (1) Felspathic Bronzite constituting lowermost part of Bastard Reef; (2) Chromite Band and Chromite; and (3) Anorthosite; in a borehole core from Schildpadnest, No. 233, Rustenburg District. (Actual Size.)

In the oxidised zone, as in the neighbourhood of Rustenburg, the platinum values have been spread over a greater thickness as the result of weathering and diffusion. Here the 8 to 10 inches of Merensky "Reef" overlying the Chrome Band carry up to 9.5 dwts. of platinum per ton, and the 18 inches of felspathic pyroxenite underlying the uppermost 18 inches up to 7.5 dwts. per ton. The average value of all the samples taken in the different workings is about 5 dwts. over a stopping width of 36 inches.

The Merensky Horizon is overlain at a distance of about 40 feet by the "Bastard Reef," to which reference has already been made. On some parts of Schildpadnest an impersistent irregular chrome band is developed along the footwall of the

"Bastard Reef" (Fig. 19). This carries small amounts of platinum.

Elandsfontein, No. 820.—A very promising sector of the horizon has also been opened up on the northern portion of this farm by the *Elandsfontein Platinum, Limited*. The development of the horizon is similar to that on Schildpadnest. It is, however, narrower, the coarse felspathic harzburgite overlying the Main Chrome Band ranging from 0 to 42 inches in thickness. It carries notable amounts of platinum throughout, and here the footwall chrome band also carries up to 6 dwts. of platinum per ton.

A typical section across the horizon shows:—

Spotted norite	.	.	.	...
Merensky "Reef"	.	.	.	2 feet
Upper Chrome Band	.	.	.	$\frac{3}{4}$ inch
Coarse felspathic pyroxenite	.	.	.	18 inches
Lower Chrome Band	.	.	.	$\frac{1}{4}$ inch
Faintly mottled footwall anorthosite	.	.	.	...

The horizon has been exposed by means of incline shafts, drives and cuttings for 4730 feet along the strike and to a depth, measured along the dip, of nearly 600 feet. Some 4015 feet of development have actually been done.

The average value of all the samples taken to date is 5.3 dwts. of platinum metals over 36 inches.

The Merensky Horizon in the Pretoria District.

It has already been pointed out that the Merensky Horizon can be traced eastward from Rustenburg to the farm Turffontein, No. 356, and that as far as this it is fairly continuous.

East of Turffontein there appears to be a gap of about 11 miles, the horizon being next met with on Elandsfontein, No. 374, situated in the Pretoria district some 22 miles west-north-west of Pretoria.

Here there was located in 1925 by the veteran geologist, David Draper, one of the most remarkable stretches of the Merensky Horizon so far discovered.

The constitution of the horizon differs from that in the Rustenburg district, firstly in that the coarse felspathic pyroxenite and the footwall chrome band which, as we have seen, are the principal platinum-bearers in that district, are

normally¹ absent, and secondly, in that the Merensky "Reef" is here of very considerable thickness. It would appear indeed that the Merensky "Reef" and the Bastard "Reef" that generally overlies it, have here coalesced to form one thick, tabular body of pseudoporphyrific pyroxenitic diallage-norite. This is somewhat coarser-grained in the lower than in the upper portion of the deposit. The strike is approximately east and west and the dip 18 degrees to the north. The hanging wall is formed of light-coloured spotted anorthositic norite merging upward into mottled anorthosite.

The footwall is formed of pure or faintly mottled anorthosite underlain by spotted anorthosite. The footwall anorthosite is, in places, much decomposed and altered to a soft white crumbly sugar-like mass that can be cut with a knife.

The Merensky "Reef" away from the joints, to be referred to, carries up to 2.5 dwts. per ton of platinum metals, but near the joints it is practically barren.

Interest centres mainly in the footwall deposit which is the principal platinum carrier. The mottled anorthosite and overlying Merensky "Reef" are traversed by a system of well-defined vertical joints striking north-east and south-west. They are fairly regularly spaced, and master-joints occur at intervals of approximately 60 feet. It is along these master-joints and at distances ranging from 4 to 25 feet below the footwall of the "reef" that the ore is found. It occurs in small irregular cigar-shaped bodies or shoots paralleling the footwall; the average depth of the ore bodies below the footwall being about 6 feet.

In the oxidised zone the ore consists of anorthosite, stained and seamed with secondary limonite, while the joints themselves are occupied by that mineral. The ore is very rich in platinum metals, assaying up to 11 ounces per ton.

Below water-level the place of the limonite is taken by grains, patches and seams of magmatic sulphides made up of the usual intergrowths of pyrrhotite, pentlandite and chalcopyrite. The sulphide ore also occurs in irregular cigar-shaped bodies lying at an average distance of 6 feet below the footwall of the Merensky "Reef." It too is very rich in platinum metals.

¹ An inconspicuous development of the footwall chrome band was noted in Trench No. 21 and in other trenches near the western boundary of the farm.

As the Merensky "Reef" adjacent to the joints is barren, there can be no question that the sulphides and platinum metals were here squeezed out of the Merensky "Reef," during the latter stages of its consolidation, into fissures opened up in the footwall. The level below the footwall at which the ore-bodies are found is evidently that at which the anorthosite was cool enough to permit the crystallisation of the sulphides and the platinum metals dissolved in them.

Part of the platinum occurring in the oxidised ore may possibly be of supergene origin and derived from the weathering of the Merensky "Reef," as in the neighbourhood of Rustenburg.

It should be stated that the mineralised joints are intersected by later barren joints.

The ore, as already indicated, is very rich in platinum metals. One bulk sample of oxidised ore returned 211 dwts. per ton. Another bulk sample of 6 tons sent to England averaged 6 ounces. Another sample returned 72 dwts. of platinum, 32 dwts. of palladium and 1 dwt. of iridium. Some of the sulphide ore also assayed over 5 ounces of platinum metals to the ton.

Unfortunately the pipe-like bodies and shoots of ore are of very limited extent, rarely exceeding 6 feet in length and 2 feet 6 inches in diameter. They are, moreover, few and far between, and no continuous ore body of sufficient magnitude to be worth working has so far been discovered.

Vissershoek, No. 45.—West of Elandsfontein no continuous stretch of the Merensky "Reef" has yet been located, but isolated patches are stated to have been found on the adjoining farm Vissershoek, No. 45.

CHAPTER XII

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

The Merensky Horizon in the Lydenburg and Pietersburg Districts.

IN the districts named the horizon has been traced at intervals from the farm Rooiboschbult, No. 1965, situated on the Springbok Flats in the southern part of the Pietersburg district, to Sterkfontein, No. 221, situated in the southern part of the Pietersburg district, a distance of roughly 100 miles.

On Rooiboschbult, the easternmost locality where it has been found in this sector of the Bushveld platinum fields, the strike is approximately east and west. The horizon does not outcrop here, but was located by prospecting beneath a considerable thickness of surface limestone probably derived from the decomposition of the Bushveld Amygdaloid by which, according to the Geological Survey Map (Sheet Potgietersrust), the surrounding area is occupied.

Between this farm and Doornvlei, No. 612, where it is next found, there is a gap of some miles. It is said to have been located in the western part of M'phatlele's Location which adjoins Doornvlei on the east. Traversing the central part of the location is a great fault along which the outcrop of the norite zone and underlying rocks has been displaced about 6 miles to the north-east. East of this fault there appears to be another gap of some 7 miles, the horizon being next met with on Zeekoegat, No. 773. From here it has been traced almost without a break, first in a south-easterly and then in a south-south-easterly direction, as far as Eerstegeluk, No. 348, a distance of about 40 miles. It has actually been opened up in this stretch on the following farms:—

Zeekoegat, No. 773; Middelpunt, No. 20; Umkoanesstad, No. 28; Brakfontein, No. 84; Klipfontein, No. 119; Pashas-

PLATE XIX



1. Portal of No. 1 Incline on Merensky Horizon, Forest Hill, No. 342, Lydenburg district.
Shows boulders of mottled anorthosite overlying hanging wall "spotted."



2. Prospecting shaft on main ore body, Blaauwbank, No. 34, Middelburg district.



kraal, No. 128; Twickenham, No. 336; Hackney, No. 337; Forest Hill, No. 342; Winnaarshoek, No. 349; Driekop, No. 170; Maandagshoek, No. 148; Onverwacht, No. 330; Winterveld, No. 424; Eerstegeluk, No. 348.

The dip in this Zeekoegat-Eerstegeluk sector ranges from 5 degrees to 25 degrees, and in places, as for instance on Forest Hill, No. 342, the horizon is disposed in gentle undulations.

A considerable amount of work was done on the horizon in the northern half of Eerstegeluk. It was found to be much broken up by faults. Between the central part of Eerstegeluk and the southern part of Tweefontein, No. 35, there is a considerable belt of disturbance. The normal westerly dip is here often seen to be reversed, and great bodies of sedimentary rocks have been floated up from the floor of the huge intrusion. In this belt of disturbance, which is some $11\frac{1}{2}$ miles wide, the Merensky Horizon appears to be missing altogether except for some small isolated outliers capping certain hills on the farm Grootboom, No. 473, and in regard to these outliers there appears to be some doubt as to whether they originally formed part of the Merensky Horizon.

The horizon in its normal development is again found in the southern part of Tweefontein, No. 35, and from here to Sterkfontein, No. 221, a distance of some 21 miles, there is an almost continuous outcrop, the outcrop striking first to the south-south-east and then almost due south. The dip in this sector ranges from 9 degrees to 30 degrees. Within it the horizon has been opened up on the farms Tweefontein, No. 35; Dwarsrivier, No. 86;

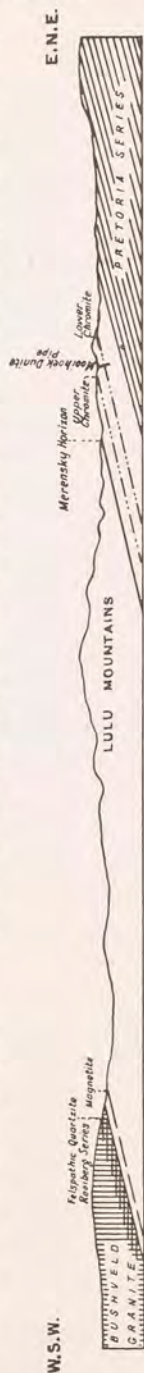


FIG. 20.—Section across the Norite Zone of the Bushveld Complex on the Lydenburg Platinum Fields.

The line of Section passes through the farms Derde Gelid, No. 141; Mooihoek, No. 147; Maandagshoek, No. 148; Garatouw, No. 467; Genokakop, No. 122; and K'Golane's Portion of Geluk's Location. (Approximate length of Section, 29 miles.)

Richmond, No. 227; Thorncliffe, No. 217; Helena, No. 220; Der Brochen, No. 226; Booysendal, No. 252; Buttonslope, No. 216; and Sterkfontein, No. 221.

Topography.—Except in the extreme north-west sector of the fields, the portion of the Norite Zone in which the Merensky Horizon outcrops is of a rugged mountainous nature. High rough-looking scrub-covered hills and ridges alternate with broad flat-bottomed valleys, the whole area being dominated north of the Steelpoort River by the range of Lulu Mountains, the great red bastions and gaunt grey precipices of which afford some very striking scenery. The highest point of the range is Thamakoosh, 6600 feet. South of the Steelpoort the dominating feature is a prominent range immediately west of the Dwars River and forming the southern continuation of the Lulu Mountains. This, for want of a better name, may be referred to as the Dwars River Range. It attains in several places an elevation of nearly 6000 feet. Four perennial streams, the Olifants, the Steelpoort, the Dwars and the Mopatsi traverse the platinum fields, and there is also a number of powerful springs on them. They are thus much better off as to water supply than the Rustenburg fields.

Facies of the Platinum Horizon.—Three main facies of the platinum horizon can be distinguished:—

- (1) The *Maandagshoek* facies, as developed in the central part of the fields. Here the horizon consists of a comparatively thick layer of Merensky "Reef" rather coarser-grained in its upper portion, which is platinum-bearing, than in its lower portion, which is barren of platinum.
- (2) The *Zeekoegat* facies developed in the northern and north-western part of the fields, where the horizon is made up normally of three layers of Merensky "Reef" separated by two thin "chrome bands."
- (3) The *Helena* facies, as developed in the southern part of the fields, in which an inconsiderable layer of coarse pegmatitic norite or felspathic pyroxenite and a thin "chrome band" are developed in the uppermost part of a thick body of Merensky "Reef," the platinum metals being concentrated here too in the uppermost part of the horizon.

The Maandagshoek Facies.—It has already been pointed out that on Maandagshoek, No. 148, the platinum horizon consists of a thick tabular body of pseudoporphyrific pyroxenitic diallage-norite carrying platinum in its uppermost portion. A section across the horizon at this locality is given in Fig. 21. It should be stated that the platinum-bearer, as elsewhere, is variable as to grade and composition, and in places encloses patches of coarse-grained pegmatitic norite.

Only the uppermost 2 or 3 feet of the horizon carry platinum and, as elsewhere in this part of the Lydenburg

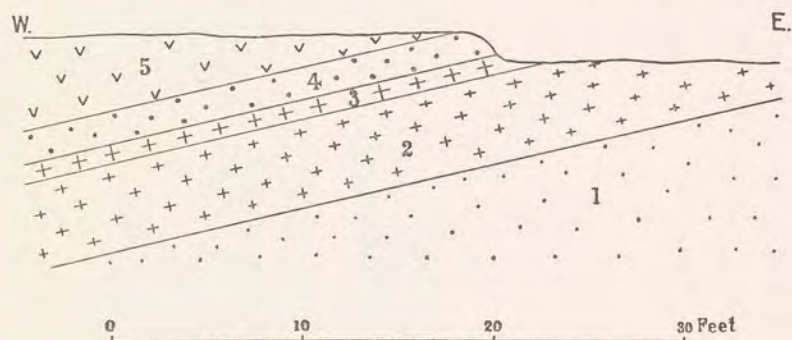


FIG. 21—Detailed Section across Merensky Platinum Horizon in Water-course 750 yards North of Southern Boundary of Maandagshoek, No. 148, Lydenburg District.

- | | |
|---|--|
| 1. Spotted Norite. | 3. Merensky "Reef" (Platinum-bearing). |
| 2. Rather fine-grained pyroxene-poor Merensky Reef. | 4. Spotted Anorthositic Norite. |
| | 5. Mottled Anorthosite. |

district, the average platinum metals content of even this portion of the horizon does not exceed 2 dwts.

On the farms adjoining Maandagshoek on the north and south the platinum-bearer has much the same character. Proceeding northward one finds that on the farm Forest Hill, for example, there are one or more narrow "chrome bands" present, and still farther north, where the Zeekoegat facies is developed, the horizon is definitely composite in character.

Zeekoegat Facies.—On the farms Zeekoegat, No. 775, and Middelpunt, No. 20, it consists, as a rule, of three distinct layers of Merensky "Reef" averaging about 18 inches in thickness separated by two chrome bands ranging from $\frac{1}{4}$ inch to 1 inch

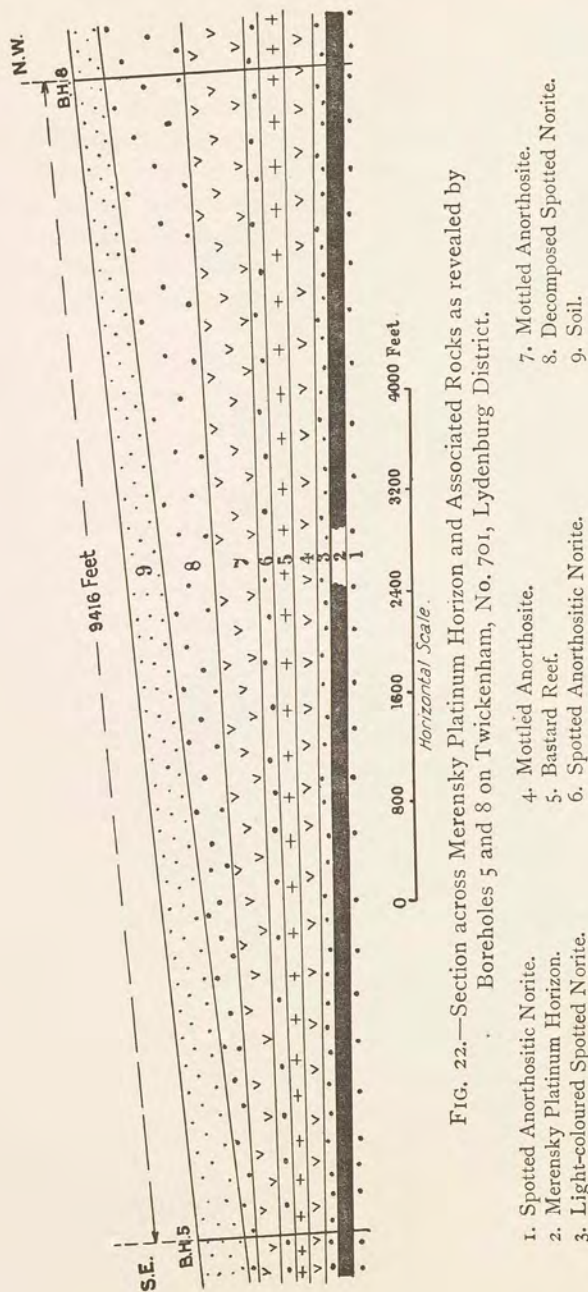


FIG. 22.—Section across Merensky Platinum Horizon and Associated Rocks as revealed by Boreholes 5 and 8 on Twickenham, No. 701, Lydenburg District.

in thickness (Fig. 23). In places, however, three chrome bands are present and the lowest layer, instead of consisting of Merensky "Reef," is made up of coarse feldspathic pyroxenite. The dip varies from 12 degrees to 24 degrees.

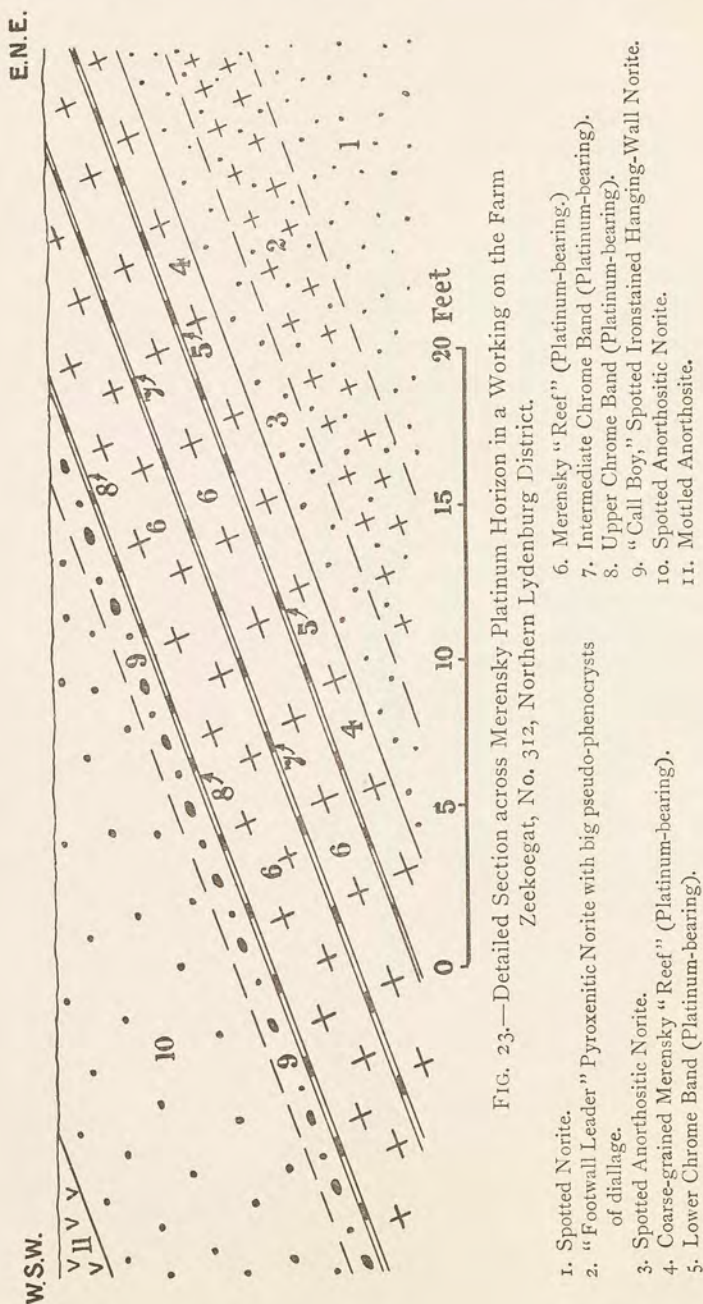
The hanging wall spotted norite, known in this area as the "Call Boy," is generally stained with secondary limonite in the oxidised zone and carries disseminated sulphides below water-level. It is barren of platinum. The footwall of the horizon is formed either of spotted anorthositic norite or spotted norite and is generally underlain by the so-called "Footwall Leader," a layer of pyroxenitic norite with big pseudo-phenocrysts of diallage. This, too, is barren of platinum.

On the farms named and also on Umkoanesstad which adjoins Middelpunt on the south-east, a great deal of exploratory work was done in the years 1925, 1926 and 1927, by the *Northern Platinums, Limited*. This work included the putting down of a number of inclines, several of which attained considerable depths, and from which, in the sulphide zone, tunnels were driven. The work proved that the horizon carries higher values in this area than elsewhere in the northern part of the Lydenburg district, but in comparison with the values obtained in the best sectors in the Rustenburg fields these values are still only moderate. Nor is there the same concentration of platinum in a definite narrow section of the horizon. The Consulting Engineer, Mr F. A. Unger, states that, as a result of all the exploratory work done, there are indicated some 700,000 tons of ore of an average assay value of 4.77 dwts. over 46 inches. The details are as follows:—

Class of Ore.	Tons.	Width (Inches).	Assay Value (Dwts.).
Oxidised . . .	630,410	47.0	4.82
Semi-oxidised . .	35,400	38.7	4.54
Sulphide . . .	17,900	54.6	3.42
	683,710	46.6	4.77

The great tonnage of oxidised ore and the comparatively small tonnage of sulphide ore developed are due to the fact that the zone of weathering extends in this area to a depth of 500 feet on the incline.

The comparatively low values in the sulphide zone are



explained as being due to the development in the sulphide ore having been done mostly in a sector where the values in both the oxidised and sulphide ore are below the average. Subsequent to the framing of the estimate, given above, further work was done in the sulphide zone in another sector, and this gave an average of 4.2 dwts. over 46.9 inches. Operations were finally suspended on 11th August 1927, and since then the workings have lain fallow.

Quite promising results were, as already indicated, also obtained in the upper chromite horizon on the farms under discussion.

West of the big fault previously referred to on Doornvlei and Rooiboschbult the horizon appears to have much the same character as on Zeekoegat, there being here also several layers of Merensky "Reef" separated by thin chrome bands. A sample taken over 46 inches across the lower part of the horizon on Rooiboschbult, No. 1965, by Mr W. E. C. Ross, Inspector of Mines, returned, on assay,

						dwts.
Pt	.	.	.	.	.	2.6
Pd	.	.	.	.	.	2.5
Ir	.	.	.	.	.	1.0

Assayer, J. Moir.

The Horizon South of the Steelpoort.—South of the big break between Eerstegeluk and Tweefontein, previously referred to, which is traversed by the Steelpoort River, a great deal of work has been done on the horizon, notably on the farms Tweefontein, Dwaarsrivier, Richmond, St Edmunds, Der Brochen and Booyseendal.

On *Dwaarsrivier*, No. 86, the outcrop was thoroughly prospected over a distance of over 8000 yards. A section across the horizon on this farm shows, in descending order:—

Spotted anorthositic hanging-wall norite	.	.	...
Platinum-bearing Merensky "Reef"	.	.	6 feet
Irregular layer of nearly pure bronzitite	.	.	$\frac{1}{4}$ inch
Chrome Band	.	.	$\frac{1}{2}$ "
Pure white labradorite-bytownite anorthosite with isolated sulphide specks	.	.	1 to $1\frac{1}{4}$ inches
Spotted footwall anorthosite	.	.	...

The average platinum content of the Merensky "Reef" on this farm is about 2 dwts. per ton, with small local enrichments.

The Helena Facies.—South of Dwaarsrivier, No. 86, the horizon generally exhibits a feature not noted farther north, a distinct layer of coarse pegmatitic norite or felspathic pyroxenite being generally present in its upper portion, and often right up against the hanging wall.

This is the case on *Helena*, or *St Edmunds*, No. 220, where the horizon has been opened up over a distance of 14,000 feet by means of adits and winzes by the *Platinum Proprietary (Lydenburg), Limited*. The horizon dips to the east or south-east at from 8 to 15 degrees, the average being about 12 degrees. Apart from two minor faults and a number of small dykes and crush zones it is remarkably undisturbed throughout. The horizon is from 8 feet 6 inches to 16 feet in thickness, the greater portion being made up of Merensky "Reef." A thin layer of coarse pegmatitic norite or felspathic pyroxenite is, however, as previously indicated, generally developed in its upper portion, and a thin chrome band is everywhere present either in the hanging wall or about 6 inches below it. The chrome band sometimes traverses the layer of coarse pegmatitic norite already referred to. A thin chrome band is also sometimes developed along the footwall of the horizon.

The platinum metals and the sulphides with which they are associated below water-level are concentrated in the uppermost 2 to 4 feet of the horizon, the lower part of the Merensky "Reef" being barren of both sulphides and platinum metals. The following are typical sections across the horizon. Both were taken in No. 3 North Adit, the first near the face and the second near the entrance.

- | | | | | |
|---|---|---|---|-----------------------|
| (1) Spotted hanging-wall norite | . | . | . | ... |
| Coarse pyroxene-rich pegmatitic norite | . | . | . | 8 inches |
| Chrome Band | . | . | . | $\frac{3}{8}$ inch |
| Merensky "Reef," sulphide- and platinum-bearing | . | . | . | 2 feet |
| Finer-grained Merensky "Reef" | . | . | . | 9 " |
| Chrome Band | . | . | . | $\frac{1}{4}$ inch |
| Mottled footwall anorthosite | . | . | . | 10 feet |
| Spotted anorthosite | . | . | . | ... |
| (2) Spotted hanging-wall norite | . | . | . | ... |
| Rather coarse Merensky "Reef" | . | . | . | 3 inches |
| Coarse pegmatitic felspathic pyroxenite | . | . | . | $1\frac{1}{2}$ " |
| Chrome Band | . | . | . | $\frac{1}{4}$ inch |
| Coarse pegmatitic felspathic pyroxenite | . | . | . | $1\frac{1}{2}$ inches |
| Merensky "Reef," platinum-bearing | . | . | . | 2 feet |
| Finer Merensky "Reef" | . | . | . | 8 " |
| Mottled footwall anorthosite | . | . | . | ... |

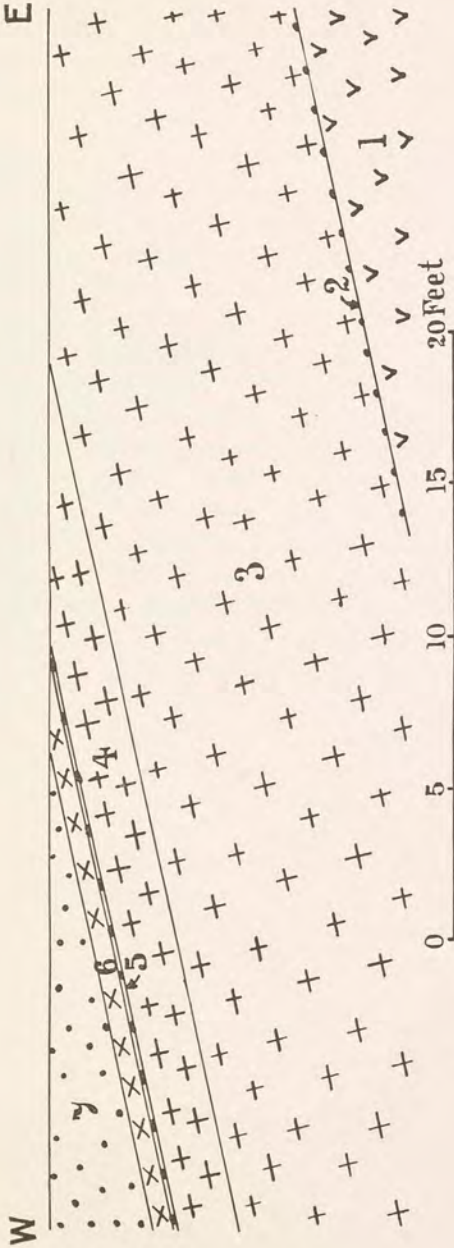


FIG. 24.—Detailed Section across Merensky Platinum Horizon in No. 3 North Adit on Helena, No. 220, Lydenburg District.

1. Mottled Anorthosite.
2. Footwall Chrome Band.
3. Rather fine-grained Merensky "Reef."
4. Medium-grained sulphidic Merensky Reef (Platinum-bearing).
5. Chrome Band (Platinum-bearing).
6. Coarse Pegmatitic Pyroxene-rich Sulphidic Norite (Platinum-bearing).
7. Spotted Norite.

Layers of bronzitite up to 8 inches in thickness enter into the constitution of the horizon in the southern part of the farm. Irregular segregations of granitic material fairly rich in quartz and containing subordinate amounts of turbid orthoclase are in places developed.

The platinum metals are, as already stated, concentrated in the upper part of the horizon. The uppermost 24 inches carry the highest values, which range up to 17.5 dwts. over this thickness. The 12 inches underlying, although in places up to 7.5 dwts. per ton, carry an average of less than 1 dwt.

The tenor of the platinum-bearing portion of the horizon varies within wide limits. The best values are obtained in the northern part of the farm. Here existing developments, according to an estimate made by the writer, indicate the presence of a block of ground containing 60,000 tons of ore averaging 5 dwts. over 24 inches, this being one of the best blocks so far opened up on the Merensky Horizon in the Lydenburg district. The Main Adit, for a distance of 245 feet in the sulphide zone, averages 5.56 dwts. over the uppermost 24 inches of the horizon and 1.5 dwts. over the 12 inches below. The bulk of the sulphide ore in this portion of the farm probably averages in the neighbourhood of 5 dwts. over 24 inches, while the oxidised ore averages about 4 dwts., being somewhat poorer in platinum metals than the sulphide ore.

In the central and southern sectors of the farm there are also some good sectors, but the average tenor is low, ranging from 4.6 to 2.4 dwts. over 24 inches.

Richmond, No. 227.—The *Platinum Proprietary (Lydenburg) Limited* have also done a considerable amount of work on this farm, where the Merensky Horizon has been traced for about 1000 yards on the south-eastern slopes of a prominent hill. The horizon has been opened up at intervals of 400 feet by three adits. Sulphide ore appears in these adits within 30 feet of the surface. A section across the horizon in the No. 1 Adit showed:—

Spotted hanging-wall norite	...
Coarse-grained Merensky "Reef"	6 inches
Chrome Band	$\frac{1}{4}$ inch
Coarse pegmatitic norite	3 inches
Merensky "Reef" carrying sulphides and platinum .	2 feet 6 inches
Merensky "Reef" free from sulphides	7 feet
Mottled footwall anorthosite	...

The best assay results were obtained in the No. 2 Adit where three samples, taken in the sulphide zone over a distance of 10 feet, averaged 6.1 dwts. over 24 inches.

Der Brochen, No. 226.—A considerable amount of work was done on this farm in 1925 and 1926 by the *Transvaal Consolidated Land and Exploration Company, Limited*. The horizon is similar in its development to that on Helena. Here also a thin band of coarse pegmatitic norite or felspathic pyroxenite carrying good platinum values is generally present in the upper part of the horizon.

Booyseendal, No. 252. Buttonshope, No. 216.—The horizon was also thoroughly prospected on these farms, but the results do not appear to have been too encouraging.

Sterkfontein, No. 221.—On this southernmost farm in the Lydenburg district on which the horizon has been opened up it is up to 24 feet 6 inches in thickness, and the dip here steepens to 30 degrees. The platinum values are low and erratic, and prospecting gave disappointing results. Here the Merensky "Reef," as on Forest Hill and other localities, is seen to send apophyses into the footwall.

CHAPTER XIII

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

The Merensky Horizon and Associated Contact Meta- somatic and Pegmatitic Deposits North-North-West of Potgietersrust

As a preliminary to the description of the important platinum deposits to the north-north-west of Potgietersrust, it will be useful to give a brief account of the geology of the area. Reference to Sheet 7 (Potgietersrust) of the Geological Survey Map of the Transvaal by E. T. Mellor and A. L. Hall, and the map (Plate XIV.) accompanying the Memoir on the Waterberg Tin Fields by H. Kynaston and E. T. Mellor, will show that to the north of Potgietersrust the great norite sill, which elsewhere was intruded in the uppermost part of the Pretoria Series, cuts diagonally downward across the rocks of the Transvaal System, being floored by progressively lower horizons until it is in direct contact with the Old Granite.¹ We have here an example of what A. L. Hall calls an igneous transgression (8).

Reference to the maps mentioned will also show that the norite was intruded partly below and partly above the rocks of the Transvaal System, much the greater part of the huge sheet lying above these rocks. Finally the mapping of the authors named, and the more recent work in the northern part of the area by E. Reuning,² H. Merensky and the present writer, have shown that in the process of intrusion of the norite huge masses of quartzite, shale and dolomite belonging to the Transvaal System were detached from the floor of the lopolith and engulfed in that rock.

The floor, where formed of dolomite, has also been much

¹ Included with the Old Granite, as shown on the maps referred to, is a younger red granite. The relation between this rock and the red granite of the Bushveld Complex is not known.

² A very valuable large-scale map of the central part of the field was prepared in 1925 and 1926 for the *Potgietersrust Platinums, Limited*, by Dr E. Reuning. This map has not been published, but copies of it are to be seen at the Mine Office of the Company.

broken and fractured with the result that there is found in places an intricate interpenetration by norite and pyroxenite of the dolomite.

Owing to the small scale of the accompanying map (Plate XXXVIII.) the geology has necessarily to some extent had to be generalised.

The sedimentary rocks flooring the lopolith and composing the xenoliths caught up in the norite magma, as might have been expected, have suffered profound alteration. This applies particularly to the dolomite and associated dolomitic marls, which have in great part been altered beyond recognition. There are to be found all gradations from but slightly metamorphosed dolomite through dolomite spotted with contact minerals and hard dense types of lime-silicate-hornfels to phanocrystalline para-pyroxenites, such as malacolite rock, diopside-hornblende-phlogopite rock and diopside-grossularite rock. Much in evidence too are ophicalcites and grey, black-spotted and greyish-green rocks composed almost entirely of serpentine. These serpentines have been derived by atmospheric weathering from forsterite-diopside rock, forsterite-phlogopite-rock and other para-peridotites. It is difficult, and in some instances impossible, to distinguish them from the serpentines derived from the olivine rocks of the Bushveld Complex. Occasionally, however, they betray their origin by the presence of coarsely crystallised calcite, or by being interbedded with layers of malacolite rock. Finally, reference must be made to coarse-grained blue-black hornblende-pyroxene rock and to green actinolite rock. It is evident that among these rocks, on which much detailed work remains to be done, there are represented both ordinary contact metamorphosed dolomites and migmatitic types that owe their origin to the transfusion from the norite magma into dolomite, rendered porous by the expulsion of carbon dioxide, of silica, magnesia, iron and other constituents. On the other hand, evidence is not wanting to show that vast amounts of sedimentary material must have been dissolved and assimilated by the norite.

The roof of the Norite Zone is formed in the neighbourhood of Potgietersrust by altered shales and quartzites of the Pretoria Series much injected with igneous material. Farther north it is formed by the red granite of the Bushveld Complex. Dykes of that rock also intersect the norite.

As to the Norite Zone itself, this is much thinner than in the Lydenburg and Rustenburg districts. It would appear that the lower part of the zone, with its familiar chromitite seams and thick layers of bronzitite, is missing altogether,¹ and that what is represented apparently corresponds with the upper three-fourths of the zone as developed elsewhere. The simplest explanation is that we have to do here with an abrupt shallowing of the Bushveld basin, as indicated in the accompanying diagram (Fig. 25), due to the intrusive transgression already referred to. On this view, the portion of the Norite Zone north of Potgietersrust represents, as we have seen, a shallow lip-like extension from the main body of the lopolith. The several rock types entering into the constitution of the

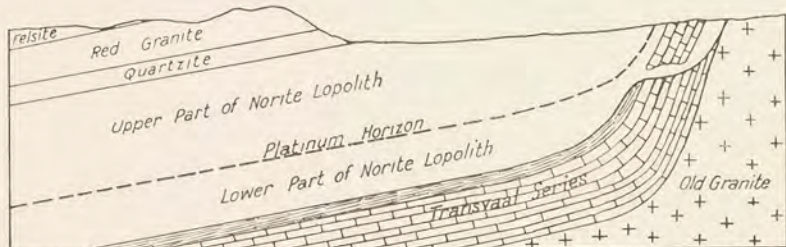


FIG. 25.—Diagrammatic Section illustrating the Presumed Relation of the Norite Zone to the Rocks under and overlying it North of Potgietersrust.

Norite Zone are, as usual, pseudostratified. The strike varies from north-west and south-east to north and south, and the dip, which is to the south-west, west-south-west or west, ranges from 20 degrees to 75 degrees. Apart from the different varieties of norite and pyroxenite, more particularly associated with the platinum deposits, which will be described in detail, reference may be made to narrow veins of graphic granite and pegmatite that are found in places cutting these rocks. They have a prevalent north-north-east trend.

The platinum deposits are here situated on the eastern side of a great flat-bottomed valley, down the western side of which the Magalakwin River pursues its sluggish course to the Limpopo. The area occupied by the norite is, as already indicated, devoid of any outstanding physical feature,

¹ One narrow seam of chromitite has been found on the eastern part of Vaalkop, No. 256, in the thin belt of norite that here separates the Dolomite from the Old Granite.

its monotony being broken only in the upper part of the zone by ranges of rugged kopjes corresponding in position with the well-known Pyramids north of Pretoria. The accompanying photographs give some idea of the physiography (Plates XX. and XXI.)

The extent of the field is considerable. The known deposits can be traced from the north-western part of the Potgietersrust Townlands to the farm Witrivier, No. 282, adjoining Drenthe, No. 984, a distance of 25 miles. Platinum has also been found on the farm Dortsland, No. 241, situated 3 miles north of Witrivier, and is stated to occur on the farms Luge, No. 108, and Teneriffe, No. 98, of which the latter is situated 24 miles north of Witrivier. Samples taken on these farms by Mr C. J. Grobler, Assistant Inspector of Mines, failed to yield any platinum, but it is clear from the specimens collected by him that the norite belt, or an offshoot from it, extends as far at least as Teneriffe.

The Platinum Deposits.

These include strictly magmatic, contact metasomatic and pegmatitic deposits. They occur on or some little distance above the floor of the main portion of the lopolith and in the sedimentary floor itself.

Platinum occurs on at least three distinct horizons. All of them are represented on the farm *Tweefontein*, No. 1033, situated 15 miles north-north-west of Potgietersrust.

The lowest deposits stratigraphically are situated on the crest and upper western slopes of Tweefontein Hill, a conspicuous bush-clad ridge on the central part of the farm, rising some 450 feet above the level of the norite flats to the west. Here, as pointed out by Dr Merensky in his unpublished report on this farm, very promising platinum values were obtained in vertical, steeply inclined and almost horizontal mineralised crush zones in a thick bed of banded ironstone occurring at the base of the dolomite series. The most important of the crush zones strikes a few degrees west of north and dips at 70 degrees to the west. Subsequent exploratory work on this zone and others connected with it proved the existence along them of lenses, eyes and irregular bodies of graphic granite and pegmatite carrying sperrylite and stibiopalladinite. To these remarkable pegmatitic deposits further reference will be

made. The platinum and palladium, as elsewhere on the Potgietersrust fields, are associated with nickel and copper, of which the latter here predominates. Analyses showed up to 4.86 per cent. of copper and 2.65 per cent. of nickel.

The deposits unfortunately proved too patchy to be worth working. It is of interest to record that most of the existing excavations are on the sites of ancient native copper workings. It is not improbable, therefore, as previously suggested, that, in the process of smelting the ore for that metal, a good deal of platinum and palladium may also unwittingly have been extracted by the pre-European workers.

The Second Platinum Horizon.—On the south-western slopes of Tweefontein Hill there was opened up in the basal part of the Norite Zone, here overlying the banded ironstones and associated quartzitic slates and quartzites, the second of the platinum horizons above referred to. This has been traced for a distance of 1700 feet. The ore-body is a thick sheet of fine-grained (0.2 to 2.5 mm.) pyroxenitic diallage-norite which is frequently seen to merge into coarse-grained bronzitite and feldspathic bronzitite. The norite and associated pyroxenite enclose big xenoliths of much contorted banded ironstone and quartzitic slate and are also seen to vein these rocks. The ore horizon thus evidently follows a xenolithic zone immediately above the intrusive contact between the norite and the altered sedimentary rocks by which it is floored.

The platinum-bearing rocks show conspicuous copper and iron stains, and in the joints traversing them are found botryoidal crusts of chrysocolla of an exquisite bright peacock-blue tint. Such crusts are a feature of the ore-body throughout its entire length.

It is to be concluded from the presence of secondary iron and copper minerals that below water-level the ore will carry the usual intergrowths of pyrrhotite, chalcopyrite and pentlandite. Big irregular patches and seams of red and brown iron opal, similar to those described by the writer on Vlakfontein No. 902 in the Rustenburg district, are in evidence in some of the tunnels. They clearly mark the position of layers and patches of massive sulphide ore. The mineralisation, which is spread over a fairly considerable thickness of rock, is sporadic, sectors showing fairly high platinum values alternating with others in which that mineral appears to be

absent. The best assays recorded were from the Rhodesia working, where one section 40 feet wide averaged 7.5 dwts. per ton of platinum metals. Here, too, however, the platinum was found to be very erratic in its distribution, and subsequent work proved the deposit to have no great economic significance.

The Main Potgietersrust or Merensky Platinum Horizon.

—Lying probably about 200 feet vertically above the horizon just dealt with—the distance cannot be precisely estimated owing to the uncertainty of the dip of the rocks of the Norite Zone in this sector—is the main platinum horizon of the Potgietersrust fields. This is taken to be the equivalent of the Merensky Horizon of the Lydenburg and Rustenburg districts. It has, as already stated, been traced at intervals for a distance of 25 miles from the Potgietersrust Townlands, to the farm Witrivier, No. 282, and is also said to be developed on the farm Zoetveld, No. 2045, south of Potgietersrust. The nature and succession of the rocks composing the horizon are variable, the only fairly constant feature being a hanging-wall of rather coarse-grained anorthositic diallage-norite, generally exhibiting a peculiar poikilitic texture. This rock outcrops prominently, thus affording a valuable horizon marker in an area where conspicuous outcrops are few and far between. As to the ore horizon itself, this conforms to the general pseudostratification, and consists, in the southern part of the area, that is on the Potgietersrust Townlands and on Turfspruit No. 990 and Tweefontein No. 1033, of a thick sheet of dark-coloured "Merensky Reef" or pseudoporphyrific diallage-norite with segregations of coarse-grained bronzitite and feldspathic bronzitite. The platinum values, ranging from a fraction of a pennyweight to 3 dwts., are confined to these pyroxenitic rocks except on Tweefontein No. 1033, where the "Merensky Reef" itself carries small amounts of the metal.

North of Tweefontein on the farm Sandsloot, No. 276, the platinum horizon over considerable distances is made up entirely of a big thickness of coarse-grained feldspathic bronzitite, identical with that of the Merensky Horizon in the Lydenburg and Rustenburg districts, but merging downward into coarse-grained pegmatitic hornblende-norite which itself rests on the characteristic fine-grained footwall norite of the area.

Farther north, in the northern part of Vaalkop, No. 256, and the adjoining farm Zwartfontein, No. 121, the coarse-grained

felspathic pyroxenite is again overlain by a considerable thickness of "Merensky Reef," but rests directly on a footwall of silicated platinum-bearing dolomite, so that we have here a fine illustration of a composite magmatic, contact-metasomatic platinum deposit.

In the central part of Vaalkop and the adjoining portion of Zwartfontein, where the lower part of the norite zone and the dolomite floor are much broken, an intricate interfingering of these rocks has taken place. There is no longer a continuous platinum horizon, its place being taken by great composite lenses and irregular bodies of coarse-grained pyroxenite, para-pyroxenite and peridotite, and serpentine derived from the latter.

The lenses conform roughly to the general pseudostratification and dip at from 50 degrees to nearly 90 degrees to the west.

Some of them are overlain by "Merensky Reef," but the biggest of the lenses, that on Zwartfontein Central, is in its northern portion over- and underlain by silicated dolomite.

Where not directly underlain by dolomite the footwall of the lenses is formed by the fine-grained norite, already referred to.

These big isolated lenses have not so far been traced beyond the northern boundary of Zwartfontein. On Drenthe, No. 982, and Witrivier, No. 282, the main platinum-bearer is again normal "Merensky Reef" which, however, carries very low platinum values. It is in part overlain by dolomite with irregular lenses of pyroxenite.

By far the most important portion of the platinum belt is that included within the limits of the farms Sandsloot, No. 276, Vaalkop, No. 256 and Zwartfontein, No. 121. It embraces three main sectors, namely:—

- (1) The Sandsloot-Vaalkop-Zwartfontein South Sector.
- (2) The Zwartfontein Central Sector.
- (3) The Zwartfontein North Sector.

1. The Sandsloot-Vaalkop-Zwartfontein South Sector.—

In this sector platinum is found in a great sinuous lens 11,000 feet in length, measured along the strike, and up to 146 feet in thickness.

In its southern portion it consists, as already stated, entirely of igneous rocks (coarse felspathic pyroxenite, and pegmatitic norite) resting on a considerable thickness of "footwall" norite.

PLATE XX



1. Collar of original No. 6 Shaft, Sandsloot, No. 276, Potgietersrust, with boulders of hanging-wall mottled anorthositic norite in the background.



2. Prospecting Trench, No. 1 Working, Vaalkop, No. 256, as it was in 1925.



In its northern portion, where it rests on silicated dolomite, it is composite in character, being made up partly of igneous rocks and partly of silicated dolomite carrying notable amounts of platinum metals over a considerable thickness. The dip is to the west and averages about 55 degrees, being, however, in places considerably lower in the neighbourhood of the outcrop (Fig. 27). The northern part of the sector carries the highest platinum values and is also the most interesting from the geological point of view. For convenience of description it is proposed, however, to deal first with the southern or main Sandsloot portion.

Southern or Main Sandsloot Section.—This has been systematically opened up for a distance of over 2000 feet by means of trenches, shafts and cross-cuts.

The ore-body is well exposed in the No. 6 workings, where a shaft has been sunk to a depth of 100 feet, and a cross-cut and tunnels driven across and along the deposit at a depth of 37 feet, the underground water-level. The main cross-cut is 130 feet long. It is partly in oxidised and partly in sulphidic ore, the surface of the water table being very uneven. The outstanding feature of this section of the ore horizon is the great thickness of the platinum-bearer. The width of the outcrop in the neighbourhood of the No. 6 workings, ranges from 175 to 180 feet, and the dip averages 55 degrees, which gives the ore-body a thickness of from 143 to 146 feet (*cf.* Fig. 26).

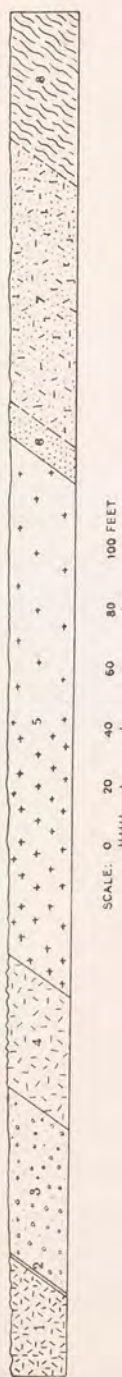


FIG. 26.—Section across the Platinum Horizon in No. 6 Working, Sandsloot, No. 276, Potgietersrust.

1. Poikilitic Anorthositic Norite (darker than 4).
2. Light-coloured Anorthositic Norite.
3. Normal Diabase-norite.
4. Poikilitic Anorthositic hanging-wall Norite.
5. Coarse-grained Platinum-bearing Felspathic Bronzite, merging downward into pegmatitic Hornblende-norite.
6. Fine-grained Anorthositic foot-wall Norite.
7. Fine-grained Anorthositic Norite with segregations of schlieren and coarser Norite.
8. Serpentinised Dolomite.

The hanging-wall is formed by the rather coarse-grained anorthositic norite previously referred to. The poikilitic texture of the rock is here very strikingly developed, the dark-coloured anhedrons of diallage scattered through it being riddled with inclusions of felspar to such an extent that it is often difficult to make out their precise boundaries. This rock passes upward into a normal mottled norite, which is itself succeeded by a darker anorthositic norite. The contact between the hanging-wall and the ore-body is rather uneven, and in the south drive from the shaft the hanging-wall norite is seen to send off a tapering vein, about 4 feet long, into the ore-body. This vein, comparable to some of those noted in the Merensky "Reef" of the Lydenburg district, indicates that the ore-body is of earlier crystallisation than the hanging-wall norite.

The footwall of the deposit is, as already stated, formed by fine-grained anorthositic norite similar to that forming the footwall of the Merensky Horizon at Forest Hill in the Lydenburg district, and also resembling superficially the anorthositic norite (Vlakfontein type) associated with the nickel deposits of Vlakfontein, No. 902. A chemical analysis of this norite is given in Chapter X. (page 119, No. IX.).

The uppermost 50 feet of the ore-body, measured horizontally, are occupied by lustrous coarse-grained hypidiomorphic granular feldspathic bronzitite, which merges downward into coarse-grained hornblende norite. The feldspathic bronzitite is very variable as to grain and composition. It encloses patches of medium-grained bronzitite and larger bodies¹ of very coarse-grained pegmatitic bronzitite composed of prisms of bronzite up to 4 inches in length. Above water-level these rocks show green copper and brown iron stains, while below the zone of weathering they are uniformly spotted with small sulphide specks.

The Ore-Bearing Feldspathic Bronzitite.—The more normal feldspathic bronzitite consists mainly of holohedral and subhedral crystals of greyish-green bronzite, or more correctly, clinobronzite, accompanied by prismatic individuals of greyish-green diallage with mantles of lustrous blackish-brown hornblende, irregular interstitial patches of greenish-white plagioclase, and flakes of dark-brown biotite. The average specific gravity of the sulphidic rock is 3.22.

¹ One such body, about 10 feet wide, is exposed in the main cross-cut 15 feet east of the centre line of the shaft.

The most interesting mineral present is the lustrous blackish-brown hornblende. This, as already indicated, forms irregular shells up to 1 mm. in thickness mantling both the diallage and the bronzite, the hornblende and pyroxenes having the c -axis in common. Like the hornblende in the ore of the Merensky Horizon, the mineral has clearly developed at the expense of the pyroxenes, as a result of reaction between them and the magmatic residuum that remained after their crystallisation. The larger hornblende individuals show zonal structure, an inner zone of brown colour being surrounded by an outer zone of pale green to practically colourless hornblende. Both types of hornblende are rather weakly pleochroic, according to the following scheme :—

Inner Zone.	Outer Zone.
Z = Brown.	Z = Green with tinge of brown.
Y = Pale brownish-green.	Y = Pale greenish-brown.
X = Very pale greenish-yellow.	X = Very pale brownish-green.

The extinction angle of both varieties is $16^{\circ}30'$. The refractive index of the brown variety was found to be as follows: $a = 1.650$, γ , very slightly > 1.630 . It is thus a common hornblende.

The felspathic bronzitite in places encloses patches of a pegmatitic nature, very rich in coarsely crystalline quartz and biotite, the latter occurring in idiomorphic plates.

The Hornblende-Norite.—Followed downward the felspathic bronzitite beyond a distance of 50 feet from the hanging wall becomes gradually poorer in bronzite and richer in felspar, diallage and hornblende, merging into a handsome, coarse-grained hornblende-norite. This consists of prismatic anhedral diallage with broad mantles of lustrous brown hornblende lying in a matrix of greenish-grey felspar carrying poikilitic enclosures of bronzite. The hornblende makes up over 10 per cent. of the rock. The hornblende-norite encloses patches of very coarse-grained pegmatitic hornblende-norite. Both types of rock are spotted with sulphide specks or with secondary iron and copper minerals resulting from their oxidation.

The Sulphides.—The sulphide specks, whether occurring in felspathic bronzitite, bronzitite or hornblende-norite, present precisely the same features. They range in diameter from 1 mm. to 1.5 cm. They are for the most part interstitial and, as in the ore of the Merensky Horizon, frequently in intimate

intergrowth with the hornblende. The sulphide specks were found by etching polished sections to consist of intergrowths of pyrrhotite, pentlandite, chalcopyrite and chalmersite. Here the primary pentlandite occurs for the most part in discontinuous shells ranging from 0.035 to 0.32 mm. in thickness, the average being about 0.11 mm., which encase irregularly rounded grains of pyrrhotite; the composite grains affording a good illustration of what Schneiderhöhn¹ has termed *mesh-structure*. Pentlandite also forms minute orientated lamellæ in the pyrrhotite.

Chemical Composition of the Ore.—The chemical analysis of a specimen of sulphidic hornblende-norite taken in the main cross-cut at a point 120 feet from the hanging-wall is given in the following table. This particular specimen was chosen because it happened to be the best-preserved material available at the time. The platinum-bearing felspathic pyroxenite, occupying the upper part of the deposit, of which an analysis is given in Chapter X. (No. IX. in Table on page 119) is poorer in lime but richer in silica and magnesia.

	Per cent.
SiO ₂	48.70
TiO ₂	0.15
Al ₂ O ₃	8.35
Cr ₂ O ₃	0.10
Fe ₂ O ₃	0.95
FeO	6.25
MnO	0.15
NiO	0.39
CuO	0.18
MgO	13.50
CaO	17.20
K ₂ O	0.80
Na ₂ O	0.95
P ₂ O ₅	0.10
CO ₂	0.20
S	1.05
H ₂ O+	2.50
H ₂ O-	0.20
Total	101.72
Less oxygen equivalent of sulphur	0.55
Total	101.17

Platinum 1.9 dwt. per short ton. 0.00032

Specific gravity=3.8. Analyst, H. G. Weall.

Platinum and nickel determinations by F. G. Green.

¹ *Metall. und Erz.*, 1922, pp. 502-508 and 517-526.

The norm calculated from this analysis is as follows:—

	Per cent.
Albite	6.81
Orthoclase	4.45
Anorthite	16.40
Nepheline	0.57
Diallage	54.04
Olivine	10.93
Apatite	0.33
Magnetite	1.39
Ilmenite	0.15
Chromite	0.15
Pyrrhotite	1.15
Pentlandite	1.37
Chalcopyrite	0.44
H ₂ O	2.50
Total	100.68

Symbol: IV. 1.2.3.1-2.

It will be noted that, according to the norm, the pyroxenite analysed contains 1.15 per cent. of pyrrhotite, 1.37 per cent. of pentlandite, and 0.44 per cent. of chalcopyrite.

Platinum is present in the sulphide ore partly as sperrylite and probably partly as cooperite. In the oxidised ore it occurs in rounded secondary grains and nuggety forms. As in the northern part of this sector, the platinum is accompanied by considerable amounts of palladium which, in the sulphidic ore, is considerably in excess of the platinum.

The sampling of No. 6 and adjacent workings proves that the best platinum values are contained in the upper 50 feet of the ore-body or, in other words, in the felspathic bronzitite, and that the hornblende-norite carries lower values which dwindle to mere traces as the footwall of the ore-body is approached.

The Northern or Vaalkop-Zwartfontein Section.—In this section, as already stated, the platinum-bearing rocks rest directly on silicated platinum-bearing dolomite. Proceeding northward from the section just dealt with, it may be studied in the so-called *Long Trench Workings*. A considerable thickness of platinum-bearing rock is here exposed, including felspathic bronzitite, "Merensky Reef," and a very handsome coarse-grained sulphidic hornblende-norite. This latter carries irregular patches of perfectly fresh sulphides at a depth of only 5 feet from the surface. The sulphide patches are up to

1 $\frac{3}{4}$ inches across and are the largest hitherto observed on the Potgietersrust or Lydenburg fields.

The richest portion of the Sandsloot-Vaalkop-Zwartfontein Sector lies immediately south and north of the Vaalkop-Zwartfontein boundary. There has here been proved a stretch some 1300 feet in length which carries high values over considerable distances. It should be stated that, as in other sectors of the Potgietersrust fields, the platinum metals are not uniformly distributed through either the igneous or contact-metasomatic rocks, the workable ore being confined to big irregular shoots which can only be defined by careful sampling. The ratio of platinum to palladium in the ore of the Vaalkop-Zwartfontein section is unfortunately rather low, being as 38:62 in the sulphide ore. Operations have on this account been temporarily suspended in this section.

Admirable sections across the composite ore-body are to be seen in the No. 1 Vaalkop and No. 1 Zwartfontein workings.

No. 1 Vaalkop.—The section exposed in this working, situated 115 feet south of the Vaalkop-Zwartfontein boundary is shown in Fig. 27.

The principal platinum bearers are the coarse feldspathic bronzitite, which merges locally into coarse pegmatitic norite, and the silicated dolomite in which it is intrusive. The "Merensky Reef" is practically barren of platinum.

The ore-bearing feldspathic bronzitite is a coarse-grained (2 to 15 mm.) rock composed mainly of bronzite. This has a slightly higher refractive index than the Sandsloot bronzite. Another point of difference between the two types of ore is that on Vaalkop hornblende is only very sparingly present in the feldspathic bronzitite and the coarse-grained norite into which in places it graduates. Both rocks are identical with the corresponding types occurring on the Merensky Horizon in the Lydenburg and Rustenburg districts. They carry up to 2 ounces of platinum metals per ton; the average tenor in the pay section is about 7 dwts.

It will be noted from the section that they are succeeded abruptly by a considerable thickness of "Merensky Reef." The "Merensky Reef" too is identical in every respect with that occurring elsewhere and, as previously shown, is also identical in composition.

The mottled anorthositic diallage-norite, by which the

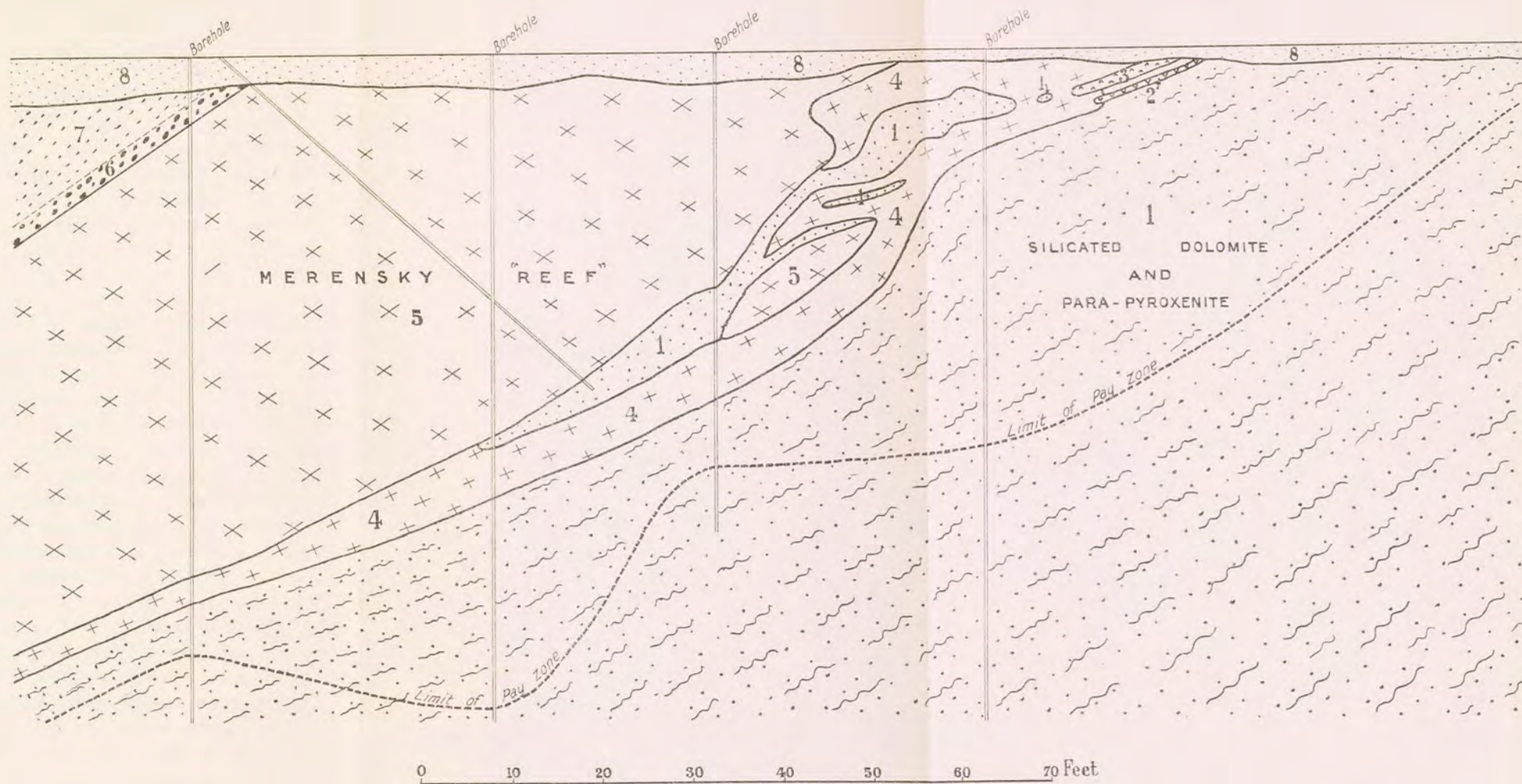


FIG. 27.—Section across the Composite Magmatic, Contact-Metasomatic Platinum Deposit exposed in No. 1 Working, Vaalkop, No. 256, Potgietersrust District.
Upper Part of Section based on observations by P. A. Wagner; Lower Part after E. Reuning.

1. Alternations of Dolomite, Serpentine and Calc-silicate Rock.
2. Granular Malacolite Rock.
3. Diopside-grossularite Rock (1-3 all Platinum-bearing).
4. Coarse-grained Platinum-bearing Felspathic Bronzite.

5. Barren Pseudoporphyrific Poikilitic Diallage-norite (Merensky "Reef").
6. Mottled Hanging-wall Norite.
7. Spotted Hanging-wall Norite.
8. Surface Soil.



"Merensky Reef" is in turn overlain, is very similar to that forming the hanging-wall in the Sandsloot Sector, the only difference being that the poikilitic texture is here less pronounced.

It is the footwall section of the deposit, however, that is of especial interest alike from a strictly geological and from an economical point of view. It will be noted that the platinum-bearing bronzitite rests on metamorphic rocks resulting from the alteration of dolomite, the contact being an irregular one. Forming the footwall in the upper part of the section (3 in Fig. 27) is a massive, compact, greyish-green diopside-grossularite rock composed of irregularly interlocking anhedral of pale yellowish-green diopside and pale greenish-yellow grossularite. Diopside is considerably in excess of grossularite. The rock exhibits "sieve" structure, the diopside holding numerous rounded and irregular grains of grossularite.

The diopside-grossularite rock overlies a sharply defined layer of granular malacolite rock, some 8 inches in thickness. This is composed entirely of interlocking crystals and rounded grains of pale greenish-yellow, to almost colourless, malacolite averaging about 2 mm. in diameter. The mineral has a refractive index of 1.6808 and an extinction angle of $38^{\circ} 30'$. The analysis of a very similar malacolite rock is given in column III. of the table of analyses on page 181.

Below the malacolite rock, and forming the footwall in the lower part of the section (1 in Fig. 27), are alternations of greyish-green mottled calc-silicate rocks rich in diopside, greyish-white black-spotted serpentine derived from fosterite-magnetite rock and almost black lime-silicate rock of uncertain composition. In the footwall of the main stope below the No. 1 trench, greyish-black lime-silicate rock is seen to be traversed by a thin vein of pegmatite, along the margins of which are developed beautiful yellow and pink contact zones composed mainly of silicified serpentine. The pegmatite itself carries fan-shaped segregations of wollastonite(?) derived from material taken up from the intruded rocks.

Near the surface the lime-silicate and associated rocks derived from the alteration of dolomite carry notable amounts of platinum and palladium for a distance of nearly 70 feet behind the contact of the bronzitite; the content of platinum metals ranges from 4 to 16 dwts. per ton. At depth the

thickness of the zone diminishes, the limits of the pay ore being clearly shown on the section. It should be stated that isolated bodies of contact metasomatic platinum ore are sometimes found in the altered dolomite footwall at distances of as much as 100 feet from the igneous contact.

The platinum metals are again associated in these contact metasomatic ores with sulphides occurring in irregular grains up to 4 mm. across. These are found on examination to consist of intergrowths of the same minerals, namely, pyrrhotite, pentlandite, chalcopyrite and chalmersite, as in the strictly magmatic ores. According to Professor Schneiderhöhn the only difference between them is that pentlandite is here the predominant sulphide and chalmersite or cubanite occurs independently of chalcopyrite in irregular grains and veinlets. No detailed account need be given of the microscopic characters of either the magmatic or the contact ores, as they are practically identical with those of Zwartfontein South, of which Professor Schneiderhöhn gives such an illuminating description. Here it need only be pointed out that the sulphides, while in part interstitial, are in part intimately intergrown with the primary and secondary silicates, the degree of intergrowth being, as Professor Schneiderhöhn points out, far more intimate than in the igneous rocks.

Professor Schneiderhöhn also gives full particulars as to the occurrence of the platinum metals in the pyroxenitic and contact-metasomatic ores of this area examined by him. In the contact ores, as already stated, platinum and palladium are almost completely segregated, the former occurring mainly as sperrylite and the latter as stibiopalladinite. Only very small amounts of these metals are here in solid solution in the sulphides.

No. 1 Zwartfontein.—A very interesting and complete section across the platinum horizon was also afforded by the No. 1 working on Zwartfontein, situated 270 feet north of the Vaalkop boundary. Unfortunately both the Vaalkop No. 1 and the Zwartfontein No. 1 trenches have been filled in by order of the Department of Mines, and the valuable evidence which they afforded is thus lost to geological science.

The composite ore-body is here made up of the lower part of a sheet of coarse-grained feldspathic bronzitite, a peculiar green serpentine rock underlying the bronzitite, and a fairly

considerable thickness of dolomite-serpentine and silicated-dolomite underlying the serpentine rock.

The coarse-grained felspathic bronzitite forms a sheet or layer of a width, measured horizontally, of about 33 feet. It is succeeded upward by a layer of "Merensky Reef" with rather isolated pseudo-phenocrysts of diallage. This layer has a width, measured at the outcrop, of 39 feet. The contact between the felspathic bronzitite and the overlying "Merensky Reef" dips to the west at 25 degrees, but the dip steepens considerably at depth. The "Merensky Reef" is overlain by the usual coarse-grained anorthositic norite.

Only the lower part of the sheet of coarse-grained pegmatitic norite and the underlying serpentine and silicated dolomite carry platinum. The platinum-bearing felspathic bronzitite more closely resembles that of the main workings on Sandsloot than that of the closely adjacent No. 1 trench on Vaalkop. As in the Sandsloot ore, there is in evidence a lustrous brownish-black hornblende which forms irregular shells enclosing the bronzitite and diallage. The felspar is again labradorite-bytownite and the ore carries the same type of brown biotite. Chromite, which is much rarer on the Potgietersrust fields than in the Rustenburg and Lydenburg districts, is here occasionally seen in stringers and small schlieren in the bronzitite.

The ore-bearing bronzitite, as already stated, overlies a green serpentine rock with isolated sulphide specks and carrying notable amounts of platinum and palladium. This is seen under the microscope to consist in order of abundance of: serpentine forming pseudomorphs after crystals and granules of forsterite, fairly well-preserved diopside, pale green spinel and pale brown phlogopite. The writer was originally in considerable doubt as to the nature of this rock, but has since come definitely to the conclusion that it is a serpentinised migmatitic forsterite-diopside-spinel-phlogopite rock probably derived from a dolomitic marl. An analysis of the rock¹ is given in column VI. of the table of analyses on page 181. It is underlain by serpentinised forsterite-grossular-spinel-phlogopite rock. These rocks also carry sulphide specks.

¹ Dr E. Reuning (59) has completely misread the writer in regard to this rock and the analysis. He is under the impression that the analysis is of the ore-bearing bronzitite, whereas it is clearly stated [(31) p. 122] that it is of the green serpentine underlying the bronzitite.

The platinum metals, as already mentioned, are confined to the lower part of the body of feldspathic bronzitite and to the serpentine and altered dolomite-serpentine in contact with it. Platinum values were proved to be present over a distance, measured horizontally, of 28 feet, the average content of platinum metals over this width being 7.5 dwts.

2. **Zwartfontein Central Sector.**—The Sandsloot-Vaalkop-Zwartfontein South Sector can be traced for only a short distance into the southern part of Zwartfontein. There is then a gap of about 1000 feet.

Beyond this one finds, set back some distance from the line of strike of the Southern Sector, the great composite lens constituting the *Zwartfontein Central* ore-body, on which mining operations are at present being concentrated. It has a length of 3500 feet and is up to 90 feet wide. The dip is from 45 to 90 degrees to the west, the average being about 70 degrees. So far it has been proved to be payable over a length of 1100 feet, and development is continually increasing this figure. It is the most important sector from the economic point of view. Not only is the tenor better than elsewhere, but the ratio of platinum to palladium is considerably higher than in the Sandsloot-Vaalkop-Zwartfontein Sector. In the oxidised ore the ratio of platinum to palladium is actually 55:45, and in the sulphide ore about 48:50. Geologically the deposit is characterised by the intimate intermingling of igneous, or ortho-pyroxenite, and metamorphic, or para-pyroxenite, derived from dolomite. The latter is sometimes difficult to distinguish from the igneous pyroxenite, but is, as a rule, darker in colour (the colour ranging from greyish-black to bluish-black) and also finer in grain. In its northern portion the ore-body is, as already indicated, both over- and underlain by altered dolomite.

A section across the deposit in the Quarry Working is shown in upward succession (*cf.* Fig. 28).

- (1) Barren lime-silicate rock.
- (2) 5 feet,¹ of blue-black para-pyroxenite carrying good platinum values.
- (3) 4 feet, of dark lime-silicate rock, barren.
- (4) 10 feet, of blue-black platinum-bearing lime-silicate rock, intersected by veins of medium-grained pyroxenite.

¹ These measurements are of horizontal widths and not true thicknesses.

- (5) 8 feet, of coarse-grained platinum-bearing feldspathic bronzitite.
- (6) 15 feet, of barren greyish-black para-pyroxenite and lime-silicate rock.
- (7) 23 feet, of coarse-grained feldspathic bronzitite with boulder-like inclusions and lenses of greyish-black lime-silicate rock.
- (8) 5 feet, of barren medium- to fine-grained spotted norite.
- (9) 4 feet, of dark lime-silicate rock forming a pendant in (8) and (10).
- (10) 13 feet, medium to fine-grained spotted norite.
- (11) 4 feet, coarse platinum-bearing pyroxenite.
- (12) Rather coarse-grained spotted norite; thickness unknown.
- (13) Poikilitic hanging-wall norite.

At a depth of 100 feet the main body of pyroxenite (No. 7 in section) is more clearly defined from the altered dolomite on which it rests. It is from 20 to 30 feet in thickness, and carries high platinum values throughout. Thus, in the No. "6. N." Cross-cut, the sampling showed an average of 5.8 dwts. of platinum and probably the same amount of palladium over a thickness of 30 feet, and in the No. "7 N." Cross-cut an average of 7 dwts. of platinum over 20 feet.

The medium- to fine-grained norite (Nos. 8 and 10 of section) is regarded on the mine as a later intrusion, but on the 45-ft. level it is seen to be veined by a coarse pyroxenite overlying it. It is probably a facies of the footwall norite, and the abnormal position of the coarse ore-bearing pyroxenite relatively to it is due to movements during consolidation. On this view the footwall and hanging-wall norites would be in contact with one another in this section. It should be noted that there are intrusions of typical "Merensky Reef" in the altered footwall dolomite east of the Zwartfontein Central ore-body.

3. Zwartfontein North Sector.—At the northern end of the Zwartfontein North Sector there is another gap, and 900 feet to the north-east there was struck the southern end of the most important of the lenses of the Zwartfontein North Sector. This particular lens is 1000 feet long and up to 70 feet wide. It dips to the west at from 35 to nearly 90 degrees.

It is again of a composite nature, being made up partly of



1. Portion of the Quarry Working, central ore body, Zwartfontein, No. 121, near Potgietersrust.



2. Treatment Plant of the Potgietersrust Platinums, Limited.



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silicated platinum-bearing dolomite. The principal ore-bearer, however, is a coarse-grained felspathic pyroxenite identical with that found in other sectors of the field. This is generally overlain by or interbanded with typical "Merensky Reef," and

	I.	II.	III.	IV.	V.	VI.
SiO ₂	2.65	33.14	50.25	44.27	41.53	36.45
TiO ₂	0.04	0.32	0.40	0.12	0.37	0.30
Al ₂ O ₃	1.56	11.32	9.34	7.14	12.11	12.40
Cr ₂ O ₃	...	...	...	0.22	0.03	...
Fe ₂ O ₃	0.24	8.01	1.81	3.82	3.17	1.90
FeO	0.41	1.93	2.84	7.20	5.04	4.40
MnO	0.38	0.27	0.20	0.21	0.20	...
MgO	22.57	24.60	9.56	22.20	19.30	23.85
CaO	34.05	11.54	25.07	10.56	12.08	10.80
Na ₂ O	0.03	0.18	0.28	0.12	0.25	n.d.
K ₂ O	0.02	0.17	0.13	0.15	0.17	n.d.
P ₂ O ₅	trace	trace	trace	0.02	0.02	n.d.
CO ₂	29.01	0.62	0.15	0.68	0.28	0.25
H ₂ O+	9.07 ¹	8.15	0.38	3.17	4.10	8.05
H ₂ O-	0.15	0.25	0.07	0.20	0.20	1.20
Ni	...	...	...	0.18	0.64	...
S	...	...	...	0.36	2.06	...
Cu	...	...	...	0.06	0.28	...
Total	100.10	100.50	100.48	100.71	101.83	...
Less oxygen equivalent of sulphur	...	...	...	0.18	1.03	...
				100.53	100.80	...

¹ The high percentage of combined water and the fact that there is not sufficient CO₂ present to satisfy the CaO-MgO leads Reuning to conclude that a hydrocarbonate is present in this dolomite.

- I. Dolomite, well in the footwall of the platinum deposits, borehole east of Sandsloot. Anal., L. Müser.
- II. Metamorphosed dolomite from outer part of contact aureole, 500 metres north of Central Section, Sandsloot.
- III. Malacolite rock, inner contact aureole, Zwartfontein North.
- IV. Coarse-grained para-pyroxenite (platinum-bearing), Zwartfontein Central Section, cross-cut west of shaft, 100-ft. level. Anal., *ibid.*
- V. Blue-black serpentinitised dolomite (platinum-bearing), Zwartfontein South. Anal., *ibid.*
- VI. Green serpentinitised migmatitic forsterite-diopside-spinel-phlogopite rock (platinum-bearing), No. 1 trench, Zwartfontein South. Anal., H. G. Weall.

rests either on silicated platinum-bearing dolomite or the fine-grained footwall norite, previously referred to. The "Merensky Reef" in this sector in places carries notable amounts of platinum, thus affording a transition to the deposit on Drenthe and Witrivier, previously referred to.

As yet very little work has been done on this sector, but it shows very promising platinum values and will doubtless eventually be systematically opened up.

Analyses of Dolomite and Platinum-bearing Contact Rocks derived from it.—Analyses of the several types of platinum-bearing contact rocks found on the Potgietersrust fields, and of the dolomite from which they have been derived, are given in the table on page 181. Analyses I. to V. are quoted from E. Reuning (59) and No. VI. from the present writer (31). The progressive silication of the dolomite, proceeding inward toward the igneous contact, is well illustrated by Analyses I. to III. Silica, alumina, iron, nickel, copper, platinum and palladium were evidently the principal constituents transfused from the norite magma. Magnesia, it will be noted, has remained fairly constant except in No. III.

Genetic Considerations.

The nature and origin of these remarkable Potgietersrust platinum deposits have already given rise to much controversy. Dr Reuning (59) regards the important lenticular and irregular bodies of coarse ore-bearing pyroxenite on Vaalkop and Zwartfontein as self-contained independent intrusions in the already consolidated footwall norite which, according to him, brought about the profound metamorphism of the underlying dolomite.

According to this view, if I read him aright, he regards them as being in no way related to the deposits on the Merensky Horizon occurring north and south of Sandsloot.

To this conclusion the present writer is definitely opposed. He maintains that in endeavouring to arrive at the correct solution of the problem the platinum deposits of the Potgietersrust district must be viewed in their entirety. In other words, the Zwartfontein deposits must be viewed in their relation to the Merensky Horizon as developed to the north and south of them and in the Rustenburg and Lydenburg districts. It has already been pointed out that on the Potgietersrust Townlands and Tweefontein, and also on Drenthe and Witrivier in the northern part of the area, where there is no evidence of any considerable disturbance, the main Potgietersrust platinum horizon consists of a big thickness of "Merensky Reef," carrying lenses and irregular bodies of coarse

felspathic bronzitite, both rocks being identical with those entering into the constitution of the big lenses on Zwartfontein. It is only on the latter farm that one finds independent intrusions of "Merensky Reef" and felspathic pyroxenite and, in places, a reversal of the relation normally existing between the several rocks entering into the constitution of the horizon.

The writer is of opinion that the process of stratiform differentiation that normally gave rise to the Merensky Horizon, as developed on the farms in the areas above named and in the Rustenburg and Lydenburg districts, was here modified by earth movements during differentiation. In places these resulted in the separation of the magma fractions that were to give rise to the "Merensky Reef" and the coarse felspathic pyroxenite respectively, and to their intrusion and consolidation as independent bodies of rock, whereas normally they occur in juxtaposition to one another.

Where these magma fractions were brought into contact with the disturbed and fractured dolomite floor, relations were further complicated by their reaction with that rock and by the intrusion into fissures opened up in it of independent bodies of these partial magmas.

The earth movements evidently ceased after the formation and crystallisation of the platinum-bearing rocks, as the overlying hanging-wall norite forms a definite continuous sheet, following all the undulation and irregularities of the composite floor of platinum-bearing rocks, fine-grained footwall norite and altered dolomite.

A. L. Hall (8) expresses the view that the considerable thickness of the pyroxenitic rocks in the Potgietersrust area is a result of the assimilation of magnesia from the underlying dolomite. The writer would point out, however, that even bigger thicknesses of these pyroxenite rocks are met with to the south-west of the Pilandsberg (26) and on Jachtlust No. 333 in the Lydenburg district, where there is no evidence of any assimilation of dolomite.

There has also been some difference of opinion as to the manner in which the mineralisation of the platinum-bearing silicated dolomite underlying the magmatic platinum deposits of the area occurred. The writer (31) ascribed it to the action of vaporous solutions emanating from the overlying norite magma which were forced into dolomite rendered porous by the

expulsion of carbon dioxide. Reuning (59) and Schneiderhöhn (see Chapter XVII.) who speak of a *Durchgasungszone*, evidently share this view. J. H. L. Vogt (58), on the other hand, opposes it on the ground that "*According to this explanation, the sulphides and the platinum in the upper part of the common deposit should be due to a magmatic segregation; in the lower part, on the other hand, the metals should be due to gaseous extraction and emanation, which at the subsequent deposition within the dolomite should have delivered ores with practically the same ratio between Fe, Cu, Ni, S and Pt as in the magmatic ore.*"

Such an accidental agreement, according to him, cannot be presumed, and he envisages a different process, namely, a magmatic intrusion of a very thin, fluid, molten sulphide.

The ratio between the elements named is, however, as stated above, not the same as in the magmatic ore, and it is at least conceivable that the gassy matte from which the sulphides and platinum metals crystallised may, at the time of intrusion, have been very near its boiling point, and that relief of pressure due to the expulsion of carbon dioxide from the contiguous dolomite may have caused temporary ebullition leading to the giving off in the vapour phase of the partial magma, rich in sulphur, arsenic and antimony, that brought about the mineralisation.

In any case the writer fails to see how a sulphide magma, however thin, could have penetrated for scores of feet and sometimes for over 100 feet into the dolomite flooring the magmatic deposits without having left any trace of its passage. He therefore adheres to the view that vaporous solutions were the main agency involved, though to some extent liquid magmatic solutions may have co-operated.

Extra-African Occurrences of Platinum in Contact Metasomatic Deposits.

In view of the great interest which the contact metasomatic deposits on Vaalkop, No. 256, and Zwartfontein, No. 121, have aroused, it should be stated that platinum-bearing deposits of this nature are also known in other parts of the world; for instance, at Sipongi, in the western part of the Island of Sumatra. Here, according to L. Hundeshagen,¹ platinum

¹ "The Occurrence of Platinum in Wollastonite, Sumatra, N.E.I." *Trans. I.M.M.*, London, 1903-4, pp. 550-552.

assays of up to 6 gms., equivalent to 2.56 dwts. per ton, were obtained from a lens of wollastonite-grossularite rock enclosed in schists of sedimentary origin near intrusions of granodiorite and augite-diorite. The wollastonite-grossularite rock has clearly resulted from the metamorphism of impure limestone.

Hundeshagen is of the opinion that the platinum, which is accompanied by palladium, gold and copper, was introduced contemporaneously with the alteration of the limestone, or very soon afterwards, by hot solutions emanating from the igneous rocks.

Another occurrence is that worked at the Nickel-Plate mine in British Columbia. Here small amounts of platinum are associated with gold in a contact metasomatic deposit of which a full description is given by C. Camsell.¹ The principal ore minerals are arsenopyrite and tetradymite. The ore-body is situated at the contact of sheets of gabbro and diorite with gently folded Carboniferous limestone associated with shales, quartzites and volcanic tuffs.

Pegmatitic and Associated Deposits on Tweefontein, No. 1033.

Brief reference has already been made to these remarkable deposits which, strictly speaking, should be dealt with under the heading of "Deposits in acid quartz-bearing differentiates of the norite magma." See page 204.

They occur in the upper part of Tweefontein Hill and have been opened up by means of the so-called upper ironstone adit and the workings connected with it. Platinum and palladium occurring, respectively, as sperrylite and stibiopalladinite are found here in irregular veins and "eyes" of pegmatite and graphic granite ranged along crush-zones in banded ironstone. The minerals named are, however, not confined to such bodies of pegmatite, and the very large crystals, already mentioned, were actually found in a seam of friable gossan, composed mainly of limonite, and evidently derived from the oxidation of pyrrhotite and other sulphides, which was struck in a winze sunk from the main shaft.

¹ Cf. Camsell, C., "Geology and Ore Deposits of the Hedley District, British Columbia," Mem. 2, Canada, Dept. of Mines, Geological Survey Branch, 1910.

In the graphic granite and pegmatite the sperrylite and stibiopalladinite are also associated with secondary limonite and malachite ore below water-level, with sulphides in the shape of pyrrhotite and chalcopyrite, the latter predominating. A specimen of graphic granite containing both sperrylite and stibiopalladinite side by side was examined by the writer and found to consist of a graphic intergrowth of quartz and felspar accompanied by acicular crystals of apatite and plates of dark biotite. The felspar, which occurs in lustrous greyish-brown anhedral up to 7.5 cm. across, is orthoclase in micropertthitic intergrowth with albite-oligoclase. The analysis of the ore-bearing graphic granite is given by Reuning (59). It is as follows:—

	Per cent.
SiO ₂	66.88
TiO ₂	trace
Al ₂ O ₃	10.86
Cr ₂ O ₃	...
Fe ₂ O ₃	1.35
FeO	1.12
MgO	0.28
CaO	0.35
Na ₂ O	2.49
K ₂ O	4.08
CO ₂	1.85
H ₂ O+	1.59
H ₂ O-	1.09
S	0.07
CuO	0.28
Total	<u>99.81</u>

These figures prove it to be very similar in composition to the graphic granite occurring as narrow veins in the differentiated zone of the norite-lopolith on Vlaktefontein, No. 902, Rustenburg district (*cf.* Wagner, 26).

The writer has not made a detailed study of these deposits, having visited them only once. It appeared to him that the ore-bodies are related in their occurrence to a very much altered, rather fine-grained mica-rich rock of uncertain composition. It is perhaps an intensely altered shale. Apophyses of basic igneous rock doubtless connected with the norite are also in evidence in some of the workings. They include intrusions of dark-coloured pyroxenite that was originally taken to be hortonolite-dunite.

Dr E. Reuning (59), who has made a careful examination of the Tweefontein deposits, and Professor Schneiderhöhn, who gives an excellent description of pegmatitic ore in Chapter XVII., are of opinion that the deposits represent the true pegmatitic facies of the Bushveld platinum deposits; or, in other words, deposits formed by residual pegmatitic vapours and solutions at a much lower temperature than obtained during the formation of either the magmatic or contact-metasomatic deposits.

According to Professor Schneiderhöhn, the three types of deposit may be arranged along a temperature gradient. At the top come the magmatic deposits formed at the highest temperature; at the bottom the pegmatitic deposits formed at comparatively low temperatures; and in between the contact-metasomatic deposits. So far the precise nature of the quartz of these deposits has not been determined, and no definite limit can therefore be assigned to the temperature of formation of the deposits. From a strictly mineralogical point of view it is of interest to record that in the specimens examined by Professor Schneiderhöhn pentlandite is absent among the sulphides. Chalcopyrite is, as already stated, in excess of pyrrhotite, which is in accordance with the conclusions reached by Buddington,¹ that chalcopyrite shows a relatively greater tendency to migrate, and to move out and farther away from the same general magma, than do pyrrhotite and pentlandite.

The Tweefontein deposits, as already stated, have no economic significance. They were systematically explored in 1925 and 1926, but no sperrylite crystals approaching in size those first found were subsequently seen.

¹ *Econ. Geol.*, 1927, p. 163.

CHAPTER XIV

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

Supergene Phenomena in Deposits on the Merensky Horizon.—In the Rustenburg and Potgietersrust districts the Merensky Horizon is never actually exposed at the surface, its outcrop being generally obscured by a variable thickness of Black Turf soil, surface limestone or other superficial deposits. In the Lydenburg district, on the other hand, it is often seen to outcrop in the hilly tracts. The outcrop, as a rule, makes no feature at the surface, the dark colour of the platinum-bearing rocks serving, however, readily to distinguish them from the light-coloured norites and anorthosites.

The oxidised ore everywhere shows stains of secondary limonite and malachite. Chrysocolla and hydrous nickel silicates are also sometimes in evidence. Analyses prove that the nickel and copper contents of the oxidised ore do not, speaking generally, differ very materially from those of the sulphide ore. This is due to the composition of the ground-water percolating through the platinum-bearing rocks, which is everywhere rich in calcium and magnesium carbonates and in colloidal silica, with the result that the soluble copper-nickel sulphates derived by oxidation from the sulphides are reprecipitated almost as soon as formed.

It might have been expected from the enormous denudation that the platinum-bearing rocks have suffered that there would have been considerable enrichment of platinum metals at the outcrop or sub-outcrop. This is not so, and in the hilly Lydenburg district the "reef" is often actually poorer at the outcrop than some distance below it. The reason of this is as follows: The platinum and palladium contained in the primary ores of the Merensky Horizon are, as Professor Schneiderhöhn has established, partly in solid solution in the sulphides. On the destruction by weathering of the sulphides they apparently go into colloidal solution in the groundwater. Where conditions are against the rapid draining

off of the groundwater and are favourable to deposition, as is the case in some parts of the Rustenburg fields, the platinum metals are redeposited in the footwall anorthositic norite immediately below the ore bodies. Where, on the other hand, as in the hilly parts of the Lydenburg district, conditions favour the rapid draining off of the groundwater, the platinum metals are carried away in solution and dissipated.

Transition from Oxidised to Sulphide Ore.—The depth to which the oxidised ore extends varies within wide limits. It depends on the configuration of the surface, on the depth of the underground water table, and on the nature and distribution of the joints and other divisional planes intersecting the ore horizon. Sulphides actually appear at depths of from 15 to 1000 feet on the dip which correspond with vertical depths of from 3 to 144 feet. Even in areas where the sulphide zone proper is entered at a considerable depth, isolated specks and patches of sulphides are often found within a few feet of the surface. The water table also shows considerable undulations. In the Kroondal-Klipfontein Mine near Rustenburg, for example, where the Merensky Horizon has been opened up over a distance of 1800 feet, the depth on the incline (9° to 10°), at which water is struck ranges from 400 to 1000 feet. The transition from oxidised to sulphide ore is, as a rule, abrupt and irregular. The sulphide ore often appears first in great irregular boulder-like masses surrounded by oxidised ore. These masses, with increasing depth beneath the surface, coalesce and give rise to continuous sheets of sulphide ore.

It has been proved throughout the Bushveld platinum fields that the oxidised ore extends to well below water-level. Thus, at Potgietersrust the average underground water-level is 20 feet, and the average depth of oxidation about 60 feet. In the neighbourhood of Rustenburg the water table stands from 40 to 60 feet below the surface, and the depth of oxidation ranges from 70 to 140 feet. In the Lydenburg district, on Zeekoegat, No. 312, the oxidised ore extends to 500 feet on the incline, far below water-level. The interesting phenomenon here referred to has been observed in other mineral deposits of the Transvaal.¹ The writer has pointed out elsewhere that it indicates a general rise in the water table due to climatic change. The present climatic period was evidently preceded over

¹ Wagner, P. A., *Econ. Geol.*, 1924, pp. 664-665.

Central South Africa by a more arid one characterised by a less abundant rainfall. During this period the underground water-level sank, and oxidation proceeded to a considerable depth. Subsequently, upon more humid conditions being once more established, the water table rose to its present position, leaving below it as evidence of its original level an irregular zone of oxidised ore.

The Form in which Platinum is Present.—Platinum is present in the oxidised ore of the Merensky Horizon partly in crystals of cooperite or sperrylite, of which the former generally only appears some little distance below the outcrop, and partly in minute colloform and nuggety grains. Some of these grains from the Potgietersrust fields have been examined by Professor Schneiderhöhn and found to exhibit a zonal structure, concentric shells of platinum surrounding a core of metallic palladium. The form and structure of the grains indicates that the metals were deposited from colloidal solutions. This is also indicated by the fact that small amounts of platinum are present in the veins of dense or colloidal magnesite intersecting the oxidised ore. Professor Schneiderhöhn is of opinion that the concretionary grains of platinum and palladium represent platinum metals that were originally in solution in the magmatic sulphides.

It has already been pointed out that the ratio of palladium to platinum in the oxidised ore is from 7 to 10 per cent. higher than in the sulphide ore, proving that palladium is more readily leached than platinum.

Evidence of Leaching and Redeposition of Platinum Metals.—One of the most interesting results of the systematic sampling of the Merensky Horizon from the surface downward in a large number of localities has been to establish that, in some areas, platinum and palladium have been leached out of the horizon on a big scale and redeposited, probably in the colloidal state, in the underlying anorthositic footwall norite. The best illustrations are in the neighbourhood of Rustenburg on Kroondal, No. 177, Klipfontein, No. 538, Waterval, No. 1023, and Vaalkop, No. 677. In this area, as already stated, the footwall anorthositic norite underlying the Chrome Band and felspathic harzburgite of the Merensky Horizon is generally found, to a depth of up to 2 feet 6 inches and more, to be stained and streaked with secondary limonite and, where this

is the case, to carry very good platinum values, ranging up to 10 dwts. and more per ton. It has also been shown that the limonite stains are of two kinds, namely, those derived from the oxidation of primary sulphides scattered sporadically through the footwall norite, and those due to the migration into the anorthositic norite from above, along joints and fractures, of ferric hydroxide derived from the weathering of the sulphides contained in the overlying platinum-bearing rocks. That these latter oxide stains and the platinum associated with them are secondary is proved by the facts:

- (1) that they are abundant only where the Merensky Horizon and the underlying norite are much fractured and closely jointed (Fig. 28A). Where such fractures are absent and the Chrome Band is "frozen" on to the footwall, the underlying anorthositic norite is free from such stains and practically barren of platinum. In other words, platinum was only deposited where, through being fractured, the footwall norite provided favourable conditions for leaching and deposition:
- (2) that as the sulphide zone is approached, the thickness of the secondarily impregnated footwall norite becomes progressively less and less, and becomes nil in the sulphide zone where the footwall norite, even where much jointed and fractured,¹ is normally barren of platinum; the platinum values, as previously indicated, being here concentrated in the lowermost 12 inches of the Merensky Horizon:
- (3) that the total amount of platinum contained in the workable part of the horizon, calculated as inch-dwts. (*i.e.*, inches of thickness multiplied by dwts. per ton of platinum metals) is practically constant in the oxidised and sulphide zones, the width of the pay ore in the sulphide zone being, as already stated, much smaller than in the oxidised zone where the platinum values were dispersed through a much bigger thickness of rock by the action of supergene waters.

¹ In this respect conditions are here fundamentally different from those on Elandsfontein, No. 374, in the Pretoria district where, as we have seen, primary platinum-bearing sulphides were forced into fissures in the footwall norite during the later stages of consolidation of the Merensky Horizon.



FIG. 28A.—Diagrammatic Section Illustrating Distribution of Supergene Platinum in Footwall of Merensky Horizon, Rustenburg District.

- | | |
|--|--------------------------|
| 1. Footwall Anorthositic Norite. | 4. Hanging-Wall Norite. |
| 2. Iron-stained Footwall Norite carrying Supergene Platinum. | 5. Black Turf Soil. |
| 3. Merensky Platinum Horizon with Chrome Band in Footwall. | J. Joints and Fractures. |

The supergene platinum, like that in the oxidised ore, occurs mostly in colloform nuggety grains which are sometimes sufficiently large to be visible to the naked eye. The platinum and palladium were thus probably transported in colloidal solution. The ratio of platinum to palladium in this secondary footwall ore is practically the same as in the oxidised ore.

It has already been pointed out that the fact of the oxidised ore extending well below water-level suggests that the present climatic period was preceded by a more arid one. Professor Erich Kaiser has made to the writer the interesting suggestion that the leaching and redeposition of platinum may have taken place during this arid period, when the groundwater was probably much richer than at present in sodium chloride and other chemically active salts.

CHAPTER XV

DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (*continued*)

Origin of the Deposits of the Merensky Horizon Type.

THESE deposits, while differing fairly considerably among themselves, have certain features in common. Perhaps the most important and interesting of them is that the platinum-bearer is invariably underlain or overlain by anorthosite or anorthositic norite, that is, by rocks rich in lime and alumina and poor in magnesia as compared with the ore-bearers.¹ Such rocks indeed, as we have seen, have come to be regarded on the platinum fields as indicators. The anorthositic rocks clearly stand in a complementary relation to the platinum-bearer. In other words, the separation of excessive amounts of lime and alumina from the parent norite magma was a necessary preliminary or corollary to the formation of sheets or lenses of norite or pyroxenite carrying platinum in association with magmatic sulphides.

It has been established that, in the differentiation of rock magmas, nickel,² and presumably platinum too, generally go with the magnesia. It is possible, therefore, as the writer has suggested elsewhere (26), that the excessive precipitation of lime and alumina which led to the formation of the anorthositic rocks may merely have established in the portion of the magma from which crystallisation was taking place, the degree of magnesia concentration requisite under certain conditions for the precipitation in quantity of platinum-bearing nickel-copper-iron matte.

The occurrence in juxtaposition of rocks differing so widely in composition as the felspathic pyroxenite and harzburgite and the pyroxenitic norite of the Merensky Horizon and the light-coloured anorthositic rocks enclosing it, is evidence that during

¹ It will be shown that at Blaauwbank, No. 34, in the Middelburg district, these relations are reversed.

² Cf. Vogt, J. H. L., *Econ. Geol.*, 1923, p. 351.

the formation of the sulphidic platinum deposits conditions were very favourable to differentiation. According to the writer's theory, this magma splitting and the concentration of platinum are alike a consequence of the presence of abnormal amounts of sulphur and other mineralisers in the particular portion of the parent norite magma from which the sulphide-bearing rocks and their associates crystallised.

The extraordinary variability of the rocks composing the horizon both as to texture and grain, the abundance of sulphides and the occasional presence in association with them of minerals such as tourmaline, quartz and fluorspar, all point to mineralisers having played an important part in this formation.

Sulphur, as is well known, is a powerful mineraliser which facilitates the differentiation of rock magmas,¹ and the platinum metals, as we have seen, are confined to the nickel-copper-iron sulphides and are actually in part in solid solution in them. It is reasonable to infer, therefore, that, owing to the concentration of sulphur and other mineralisers in certain of the magmatic fractions, these were kept in a liquid state for an abnormal period, and in consequence underwent pronounced differentiation. At the same time the small amounts of platinum contained in the magma were dissolved and concentrated in the droplets of matte which the sulphur formed with the nickel, copper and iron that it extracted from the magma, the matte droplets being themselves concentrated in the magnesia-rich fraction that gave rise to the Merensky Horizon. This fraction in all probability was of the nature of a magmatic residuum left over in the general differentiation process.

That the Merensky Horizon, whether entirely made up of Merensky "Reef" or whether composite in character and made up of the most diverse rocks, has the same chemical composition, proves that the magma fraction from which it crystallised had everywhere much the same character, but that in some places it consolidated under conditions admitting of more far-reaching differentiation than in others.

On the theory here outlined, the magmatic concentration of platinum in the deposits under discussion was a necessary accompaniment, in those portions of the parent norite magma containing appreciable amounts of the metal, of a type of

¹ Cf. Wagner (26, p. 82).

differentiation that gave rise on the one hand to norite or pyroxenite carrying magmatic sulphides, and on the other to anorthositic norite or anorthosite. So far as the Merensky Horizon itself is concerned, it is not necessary to assume that the process was operative throughout the entire vast extent of the lower part of the norite zone, but merely that identical processes of differentiation repeated themselves at more or less the same level.

The probable course of the crystallisation of the sulphidic ores is very clearly outlined by Professor Schneiderhöhn in Chapter XVII., and to his masterly description there is nothing to add. The metals, as previously stated, were probably in part at least in solution in the sulphides in a gaseous state. Where crystallisation proceeded quietly they ultimately entered into solid solution in them; where it was disturbed the platinum metals were expelled and dissipated.

Origin of the "Bastard Reef."—It has been pointed out that the Merensky Horizon is overlain over wide areas in the Rustenburg and Lydenburg districts, at a distance of from 30 to 40 feet, by a "Bastard Reef," similar to the "Main Reef" in petrographic character, and also over- and underlain by anorthositic rocks. The "Bastard Reef" thus clearly owes its origin to differentiation of the same type as that which gave rise to the main horizon. It, however, normally carries only traces of platinum. It is to be concluded from this that when the process of differentiation normally accompanied by the magma segregation of platinum came to be repeated in the portion of the norite magma in question, this had been so depleted of that metal that a degree of platinum concentration comparable with that in the main horizon could not be attained.

No Evidence of Gravity Control.—While the Bushveld Complex as a whole affords an admirable illustration of gravity differentiation and of density stratification, and the writer has shown that in the formation of the Vlaktefontein nickel deposits gravity was a controlling factor, the deposits of the Merensky Horizon in many localities present evidence directly contrary to that view. This applies, for example, to certain sectors lying north of the Pilandsberg, where, as we have seen, the heavy chromitite and the felspathic harzburgite carrying the highest platinum values occur in the uppermost part of the horizon.

The same is true of the horizon as developed on Sandsloot, No. 276, in the Potgietersrust district, where felspathic bronzitite carrying platinum occupies the upper part of the horizon, while the lower part is occupied by barren hornblende-norite. The specific gravity of the former rocks ranges from 3.2 to 3.23, and that of the latter from 3.08 to 3.11.

Some agency other than gravity must here clearly be invoked. It is just possible that a process again of ore flotation by gas bubbles may have been operative. The magma fractions that gave rise to the deposits under consideration were, as we have seen, fairly rich in water, H_2S and other mineralisers. It is conceivable, therefore, that the platinum-bearing matte droplets, chromite and heavy silicates were carried to the upper limit at which solid matter could exist by minute adhering bubbles of these gases.¹ This may possibly account for such phenomena as that of the Chrome Band cutting indiscriminately across large crystals of bronzitite and other silicates. (Cf. Fig. 14.)

In this connection it is of interest to record that John Stansfield² has recently given us an entirely new conception of the possible nature of silicate-sulphide magmas. According to him they are colloidal emulsions of sulphide and oxide globules dispersed in a silicate fluid.

¹ Cf. Goodchild, W. H., "The Evolution of Ore Deposits from Igneous Magmas," *The Mining Magazine*, London, 1918.

² *Assimilation and Petrogenesis: Separation of Ores from Magmas*, Valley Publishing Co., Urbana, Illinois, 1928.

CHAPTER XVI

PLATINUM DEPOSITS OF THE BUSHVELD IGNEOUS COMPLEX (continued). MISCELLANEOUS DEPOSITS

Deposits of the Merensky Horizon Type occurring below and above the Horizon in the Lydenburg District.

Dwarsrivier, No. 86.—Lying on a fairly well-defined horizon, about 40 feet below the Merensky Horizon in spotted anorthosite on this farm, are lenses of dark-coloured platinum-bearing rock up to 30 feet in length and up to 4 feet in thickness. The platinum-bearer, which is variable in character, is in part pseudoporphyrific diallage-norite indistinguishable from that of the Merensky Horizon; in part coarse-grained felspathic pyroxenite made up mainly of big prismatic individuals of bronzite. Some of the lenses were proved to be fairly rich in platinum, but their limited extent deprives them of any economic significance.

Onverwacht, No. 330, and Other Farms.—The same horizon has been picked up on Onverwacht, No. 330, Driekop, No. 170, and Helena or St Edmunds, No. 220. On the last named farm, however, there are also definite intrusions of platinum-bearing pyroxenite in the footwall anorthosites of the Merensky Horizon.

Kalkfontein, No. 22.—On the farm Kalkfontein, No. 22, adjoining Dwarsrivier, No. 86, lenses and stratiform bodies of platinum-bearing pseudoporphyrific diallage-norite are found on an horizon apparently lying some 500 feet above the Merensky Horizon. The platinum-bearer is for the most part indistinguishable from that of the Merensky Horizon. As in the latter, the hanging-wall is formed of light-coloured spotted norite and the footwall of rock of the same character. The deposits fall within the disturbed portion of the Norite Zone, previously referred to. The dip in some of the workings is to the east, that is, in the opposite direction to the normal dip, but in others it is to the west, and in yet others to the north. In trench No. 16 the ore-body is traversed by a reverse strike fault which has brought the ore into juxtaposition with the hanging-wall spotted anorthosite. The ore-bodies range

in thickness from a foot to 7 feet. The platinum content is very variable. A sample taken by the writer in trench No. 13, over a thickness of 42 inches, gave 10 grains per ton. Another, over a thickness of 40 inches in trench "B," returned 6 dwts. per ton. The platinum of the latter occurrence as seen in the pan is in the form of minute square plates of tin-white colour and brilliant metallic lustre. According to Dr J. Moir, it is unusually rich in palladium. This probably accounts for its white colour. No considerable workable deposits have been located on this horizon.

Deposits of the Steelpoort Park Type.

Deposits of this type occur in no fewer than five horizons in the upper part of the Norite Zone on portions "B," "C" and "F" of the farm Steelpoort Park, No. 246, lying south of the Steelpoort River in the Lydenburg district. The ore-bearer, as already stated, is a medium-grained spotted felspar-rich norite uniformly interspersed with small sulphide specks.

The deposits were originally assumed to be stratiform.¹ Further work, however, proved that the platinum-bearing norite does not occur in continuous layers but as irregular boulder-like masses. These rarely exceed 8 feet in length and 18 inches in thickness, and generally are very much smaller.

The boulder-like ore-masses which, as already stated, occur on definite horizons, conform to the general pseudostratification, the dip averaging 15 degrees to the west-north-west. They are either overlain by lenticular layers of spotted anorthosite or completely enclosed in anorthosite which itself sometimes carries sulphides and traces of platinum.

The platinum content of the sulphidic norite ranges from 0.4 to 2.5 dwts. per short ton. The deposits have no economic significance.

Thin sections of the sulphidic norite prove that it consists of an allotriomorphic granular aggregate of labradorite $\text{Ab}_{35}\text{An}_{65}$ and bronzite accompanied by subordinate amounts of green hornblende and diallage. It is thus a true norite. The outstanding feature of the ore, however, in comparison with all the platinum-bearing rocks hitherto described, is its richness in soda-lime felspar which is greatly in excess of bronzite. This is very clearly brought out by the norm calculated from

¹ Cf. Wagner, P. A., *Trans. Geol. Soc. S. Africa*, 1925, p. 127.

the analysis given below. It was to be expected from the position of the ore-bodies so high up in the norite lopolith, which, as the writer has shown elsewhere,¹ is stratified according to density.

The sulphides occur interstitially to the silicates, but are also seen in places to embay the bronzite as if they had replaced that mineral. The specks, which are up to 1.5 mm. across, are composed of irregular intergrowths of pyrrhotite, nickeliferous pyrite, pentlandite and chalcopyrite. It will be noted from the analysis and from the norm calculated from it that the proportion of copper to nickel, or in other words, that of chalcopyrite to pentlandite, is much higher than in the magnesia-rich rocks hitherto dealt with. This again was to be expected from the investigations of J. H. L. Vogt, who has shown that in the magmatic nickel-copper ores of the type under discussion, the ratio of nickel to copper is proportional to the magnesia content of the parent rock.²

A sample of the sulphidic platinum-bearing norite from trench No. 6, portion F, Steelpoort Park, was analysed with the following result:—

	Per cent.
SiO ₂	47.70
TiO ₂	0.10
Al ₂ O ₃	21.80
Cr ₂ O ₃	0.10
Fe ₂ O ₃	2.05
FeO	6.00
MnO	0.10
NiO	0.39
CuO	0.38
MgO	6.65
CaO	10.95
K ₂ O	trace
Na ₂ O	2.50
P ₂ O ₅	0.10
CO ₂	0.05
S	1.35
H ₂ O +	trace
H ₂ O -	1.35
	101.57
Less oxygen equivalent to sulphur	0.58
Total	100.99
Specific gravity	2.98
Analyst, H. G. Weall.	

¹ Memoir 21, *Geol. Survey, Union of S. Africa*.

² Cf. *Econ. Geol.*, 1923, p. 351.

The norm of the rock calculated from this analysis is as follows:—

	Per cent.
Albite	20.96
Anorthite	48.37
Diopside	3.99
Bronzite	16.46
Olivine	2.43
Apatite	0.33
Magnetite	3.02
Ilmenite	0.15
Chromite	0.15
Pyrrhotite	1.44
Pentlandite	1.37
Chalcopyrite	0.87
H ₂ O	1.35
Total	<u>100.89</u>

Symbol: II. 5.4.4-5.

Deposits of the Minsk's Claims Type (Lydenburg District).

The deposits referred to are situated on Minsk's Claims on portion A of the huge farm Steelpoort Park, No. 246. They take the form of small irregular bodies of coarse-grained felspar-rich sulphidic diallage-norite, enclosed in medium-grained spotted norite. They lie a short distance below one of the great stratiform segregations of titaniferous magnetite that are so characteristic a feature of the upper part of the Norite Zone. Whether the ore-bodies are of the nature of segregations or whether they represent later intrusions in the spotted norite it is impossible to say from the existing exposures, but the former alternative appears the more probable. The section exposed at the northern end of the main workings is shown in Fig. 29. A sample over a thickness of 42 inches in the portion of the working here represented, taken by Mr C. J. Grobler, Assistant Inspector of Mines, assayed 5.5 dwts. of platinum per ton.

The ore-bearer is a lustrous bluish-green rock composed of big tabular crystals of rather acid labradorite, irregular grains of brownish green diopside with rod-like inclusions parallel to (100) and (001), anhedral of bronzite and smaller granules of magnetite. The sulphide specks with which the rock is sprinkled are up to 0.8 centimetres across, and are made up as

usual of intergrowths of pyrrhotite, pentlandite and chalcopyrite. It will be noted that the sulphidic platinum-bearing norite encloses a thin seam of titaniferous magnetite.

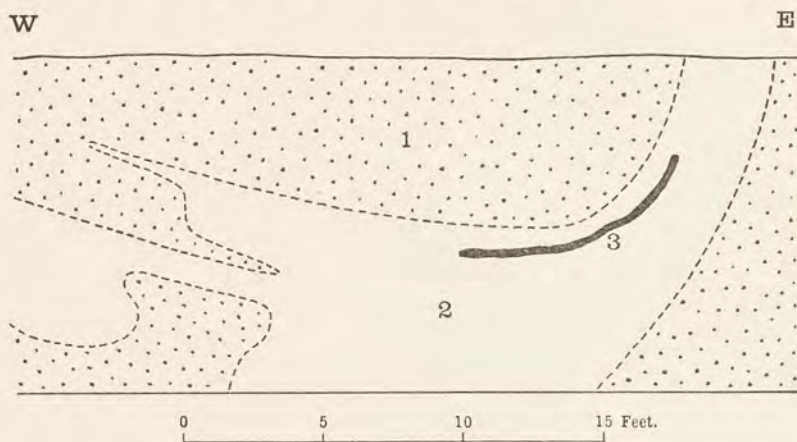


FIG. 29.—Section exposed at North-Western End of Main Working on Minsk's Claims, Steelpoort Park, No. 246, Lydenburg District.

- | | |
|--------------------|--|
| 1. Spotted Norite. | 2. Platinum-bearing Sulphidic Diallage-norite. |
| | 3. Titaniferous Magnetite. |

Deposit of the Blaauwbank Type.

These deposits are of interest in that they present practically the reverse of the conditions presented by the Merensky Horizon. Whereas on the latter platinum occurs in dark-coloured norite and allied rocks intercalated with light-coloured anorthosites, on Blaauwbank, No. 34, the platinum carrier is a light-coloured anorthositic quartz-bearing norite forming boulder-like, sheet-like and irregular carrot-shaped segregations in dark-coloured diallage-norite.

The farm is situated 35 miles north-north-west of Middelburg, and is occupied partly by norite belonging to the uppermost part of the great lopolith and partly by red granite. The platinum deposits are ranged along a fairly well-defined zone traversing the south-eastern part of the farm in a north-east and south-west direction. Most of them are small, but the Main Body (Fig. 30), on the claims of the Lydenburg Central Platinum Company, Limited, has been proved by underground exploratory work to be of fairly considerable size. Platinum,

it should be stated, occurs in these deposits mainly in minute brilliant cubo-octahedrons of sperrylite associated with the usual magmatic sulphides. The sulphides are irregularly distributed through the ore-bodies, and, as the platinum metals go with the sulphides, the deposits are also patchy as to platinum values.

The main ore-body, already referred to, is irregularly oval in ground plan, and has been proved to extend to a depth of 48 feet. It is almost bisected by a north to south trending fault by which the eastern side of the ore-body has been let

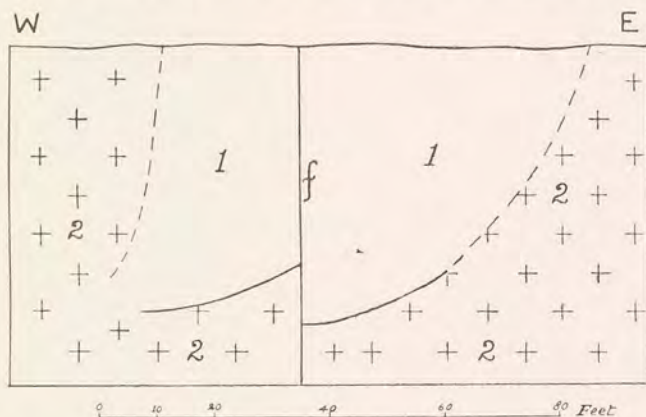


FIG. 30.—Section through Main Ore-body on Blaauwbank, No. 34.
Middelburg District.

1. Anorthositic Platinum-bearing Quartz-norite.
2. Dark-coloured Diallage-norite.

down about 10 feet. In the central portion of the body, where a vertical shaft was put down, it carries fairly high platinum values from the surface to a depth of 22 feet, assays showing up to 13 dwts. of platinum metals per ton. Below 22 feet there was a considerable drop in the platinum content of the ore, the average tenor being about 3 dwts.

Among the sulphides chalcopyrite again predominates. Thus a representative bulk sample showed 0.4 per cent. of copper and 0.1 per cent. of nickel. It will be noted, however, that in the analysis given below nickel is in excess of copper. The ratio between the two metals is thus apparently not constant.

Thin sections of the platinum-bearing anorthositic quartz-norite of this occurrence show that it is composed mainly of

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tabular and lath-shaped crystals of very much altered, twinned labradorite accompanied by subordinate amounts of interstitial quartz and quite subordinate amounts of chlorite, evidently derived from grains of an original magnesian constituent. Composite sulphide specks made up of intergrowths of chalcopyrite, pentlandite and pyrrhotite are scattered fairly uniformly through the rock and are, as usual, moulded on the silicates. The chemical analysis of a specimen of the ore from the main body of the claims of the *Lydenburg Central Platinum Company, Limited*, gave the following result:—

	Per cent.
SiO ₂	46.95
TiO ₂	0.30
Al ₂ O ₃	24.70
Fe ₂ O ₃	2.55
FeO	4.30
CuO	0.50
NiO	1.00
CaO	10.90
MgO	0.80
K ₂ O	0.50
Na ₂ O	2.35
P ₂ O ₅	0.15
CO ₂	0.05
S	2.70
H ₂ O+	3.65
H ₂ O-	0.10
Total	101.50
Less oxygen equivalent of sulphur	1.35
Total	100.15

Analyst, H. G. Weall.

Occurrences in Acid Differentiates of the Norite Magma.

The most important deposits under this heading are the platinum and palladium-bearing pegmatites on Tweefontein, No. 1033, Potgietersrust district, which have already been described. Several other occurrences more or less closely allied in character are known in the Lydenburg and Middelburg districts. These, however, are within the Norite Zone itself, whereas the Tweefontein deposits, as pointed out, are in banded ironstone flooring the norite. See page 185.

Maandagshoek, No. 148, Lydenburg District.—Lying about 200 feet vertically above the Merensky Horizon on this farm is a lens of a remarkable hornblende-rich pegmatitic rock about 60 yards in length. The pegmatitic rock consists of big crystals of lustrous brownish-black hornblende and yellowish-brown diallage lying in a matrix of quartz and white felspar. The hornblende and diallage, which are often in parallel intergrowth, are similar in their optical properties to the hornblende and diallage found in certain of the hortonolite-dunite occurrences of this area. There is thus a possibility, as previously suggested, of there being a complementary relation between the two types of rock. The hornblende-rich pegmatite is spotted with small sulphide specks and carries from a trace to 1.8 dwts. of platinum per ton.

A similar body of hornblende-bearing pegmatitic rock is exposed on the eastern slopes of the Lulu Mountains on the farm Garatouw, No. 467.

Lagersdrift, No. 82, Middelburg District.—On this farm small amounts of platinum have been found to be present in what appears to be a segregation vein of a granitic rock composed of quartz, felspar and biotite which intersects norite and pyroxenite enclosing seams of chromite. There is a similar occurrence on the farm *Sterkfontein*, No. 222, in the southern part of the Lydenburg district.

CHAPTER XVII

THE MINERAGRAPHY, SPECTROGRAPHY AND GENESIS OF THE PLATINUM-BEARING NICKEL-PYRRHOTITE ORES OF THE BUSHVELD IGNEOUS COMPLEX

By Professor Dr H. Schneiderhöhn, Freiburg-in-Br.

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I. *Rustenburg District*—
 Schildpadnest, No. 233: 6 specimens collected by
 Dr P. A. Wagner.
 Vlakfontein, No. 902: 5 specimens collected by
 Professor E. Kaiser and Dr H. Lotz.

Schildpadnest, No. 233: 6 specimens collected by
Dr P. A. Wagner.
Vlakfontein, No. 902: 5 specimens collected by
Professor E. Kaiser and Dr H. Lotz.

Dwarsrivier, No. 86: 6 specimens collected by Dr
P. A. Wagner.
Mooihoek, No. 147: 11 specimens collected by Dr
E. Reuning.

66 specimens collected by Dr E. Reuning from :
 Sandsloot, No. 276, South Section ;
 " Central "
 Zwartfontein, No. 121, South Section ;
 " Central "
 " North "
 Tweefontein, No. 1033 ;
 Vaalkop, No. 256.

The Ores of the Merensky Horizon on Schildpadnest, No. 233.

- (a) Medium-grained pseudoporphyrritic diallage-norite (Merensky "Reef"), with low platinum content.
- (b) Chromitite constituting the "Chrome Band." This averages an inch in thickness and is rich in platinum.
- (c) Coarse-grained feldspathic harzburgite rich in sulphides and fairly rich in platinum.
- (d) Several specimens of coarse sulphide intergrowths forming segregations in the feldspathic harzburgite.

Dr Wagner has given a full description of these several rocks and their field relations in an earlier chapter. My own investigations completely confirm these descriptions and the earlier descriptions of the Rustenburg ores published by him. The latter are also confirmed, and to some extent amplified, by Reuning (59).

The Sulphidic Ore Minerals of the Felspathic Harzburgite and Merensky "Reef."

The felspathic harzburgite, as already indicated, contains the most sulphides, the Merensky "Reef" being poorer both in sulphides and platinum. The manner of occurrence of the sulphides is precisely the same in both rocks. They are found as irregular patches and grains occupying the interspaces of the silicates, and also in smaller grains along the margins of the individual silicate grains. At the contact between the sulphides and the primary silicates—olivine, diallage, bronzite and labradorite—reaction rims have generally developed at the expense of the silicates. These, in the case of the ferromagnesian minerals, consist mostly of hornblende, and in the case of the plagioclase usually of biotite. The hornblende and biotite are orientated crystallographically with the minerals from which they have developed. The sulphides are intimately intergrown and interfingered with these reaction minerals.

In the specimens under description the sulphide patches are up to 3 cm. across but, as a rule, they do not exceed a few millimetres and often attain only microscopic proportions. Under the microscope one finds that, in addition to their occurrence as intergranular bodies, the sulphides occasionally also appear as inclusions in the silicates.

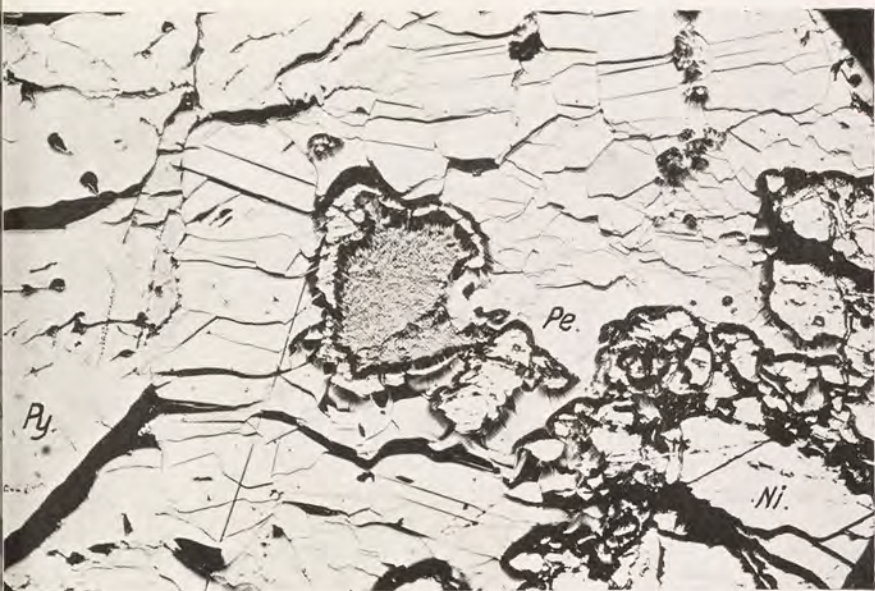
The following minerals were found to enter into the constitution of the sulphide aggregates:—

Nickeliferous Pyrite.	Chalcopyrite.
Pyrrhotite.	Cubanite or Chalmersite.
Pentlandite.	Graphite.
An Unidentified Ore Mineral.	Millerite.

In addition there occur as inclusions in the aggregates the several primary silicates mentioned above, the secondary reaction minerals, hornblende and biotite, and finally, as a hydrothermal alteration product of the olivine and bronzite, serpentine. The individual ore minerals may next be considered.

Nickeliferous Pyrite.—There are numerous references in geological literature to nickel-bearing and cobalt-bearing pyrite, as will be seen by referring to Doelter's *Handbuch der Mineralchemie* (67).

In mineragraphic descriptions of deposits of nickeliferous



1. Polished section by reflected light, unetched. $\times 150$. Ore of Merensky Horizon, Schildpadnest, No. 233, Rustenburg district; textural relations of sulphides. At centre of field annular replacement residuals of nickeliferous pyrite in pentlandite (Pe), the nickeliferous pyrite itself enclosing an irregular grain of pyrrhotite intimately veined by serpentine and hydrothermal carbonates. These minerals also occupy octahedral cleavages of the pentlandite. On left of field, more nickeliferous pyrite (Ni); on right, big individual of pyrrhotite (Py).



2. Polished section by reflected light, unetched. $\times 200$. Ore from same locality. Deeply corroded grain of nickeliferous pyrite in pentlandite.



pyrite a similar mineral is referred to as *Bravoite* (66 and 75), but it is clear from these descriptions that no mineragraphic or X-ray spectrographic examination of carefully analysed specimens of such nickeliferous and cobaltiferous bi-sulphides has as yet been undertaken. Until this has been done I prefer to refer to the mineral under description by the non-committal name *Nickeliferous Pyrite*.

Optically it is quite isotropic. The reflectivity and colour are identical with those of normal pyrite. The reflectivity was very carefully tested by means of a new reflectometer designed by me and manufactured by the firm of E. Leitz, Wetzlar (88). Using light of different wave lengths it was found, within the limits of experimental error, to be exactly the same as that of pyrite.

In its behaviour toward etching reagents it differs slightly from pyrite in that it is more difficultly soluble in all the reagents listed by me (85) than that mineral. It hardly reacts with nitric acid and even a solution of potassium permanganate acidified with sulphuric acid barely affects it. To the significance of this I shall refer later.

The nickeliferous pyrite always occurs in allotriomorphic grains and ragged replacement residuals ranging from 10 to 500 μ across. Grains differing greatly in size often occur in close contiguity to one another. Small rounded grains are frequently seen to be aligned in long rows behind one another. The bigger grains always show deep bays and marginal fractures into which the other sulphides have penetrated (Plates XXII. and XXIII.) The nickeliferous pyrite is commonly found enclosed in pentlandite. Where this is the case it sometimes forms ring-shaped bodies in turn encasing smaller rounded grains of pyrrhotite, which may be intimately veined with secondary serpentine (Plate XXII.1). It is also found imbedded in the large grains of massive pyrrhotite, but practically never in the bigger patches of chalcopyrite. The ragged residuals of nickeliferous pyrite enclosed in pyrrhotite and pentlandite are sometimes bordered by a narrow fringe of chalcopyrite. Inclusions of other sulphidic ore minerals in the nickeliferous pyrite were never noted, nor could any inhomogeneity be detected in it under the highest powers of magnification, using both ordinary and polarised light.

The nickeliferous pyrite is clearly the earliest formed of

the sulphide minerals. It is corroded and replaced by all the other sulphides, and of the crystal outlines that it may well originally have shown no trace remains.

The samples examined contain no younger generation of pyrite such as P. A. Wagner (26) has described from Vlakfontein, or of marcasite.

Pyrrhotite.—Pyrrhotite occurs in big granular masses and often forms subhedral individuals several millimetres across, and characterised by a uniform cleavage, which coalesce to form bigger grains. The larger individuals are, speaking generally, remarkably free from inclusions of other sulphides apart from secondary pentlandite.

A series of well-defined cleavage lines are always developed in the mineral in a direction that, judging by their optical orientation, parallels the basal pinacoid (0001). They, and another series of divisional planes intersecting them at right-angles, are occupied by thin veinlets of secondary silicate and carbonate matter. These present in cross-section a remarkable appearance recalling skull sutures (Plates XXIII. and XXIV.1). With the highest powers of magnification it becomes apparent that, whereas the cleavage parallel to (0001) is well developed, that at right-angles to it is only very imperfectly developed. The thin silicate and carbonate veins following the latter direction in consequence everywhere show a tendency to turn sharply back at right-angles into the better defined cleavage planes parallel to (0001). This gives the veins, when seen in transverse section, their curious sutured character.

I regard the silicate and carbonate matter occupying the cleavage cracks in pyrrhotite as well as in pentlandite as hydrothermal alteration products of the silicates. Films of chalcopyrite are sometimes developed along both sides of the predominant silicate bands and thus they are parallel to the basal plane (Plate XXIII.1).

Exsolution or unmixing lamellæ of pentlandite are found imbedded in the pyrrhotite at right-angles to the predominant carbonate and silicate bands, and thus lie in the zone of the crystal faces parallel to the *c*-axis. They take the form of very thin plates ranging from 2 to 4 μ in thickness and from 20 to 50 μ in length (Plate XXIII.2); or they may consist of aggregates or bundles of closely spaced parallel lamellæ showing pointed brush-like terminations at either end, where they



1. Polished section by reflected light. $\times 200$. Microtexture of pyrrhotite in ore of Merensky Horizon, Schildpadnest, No. 233. Serpentine and secondary carbonates are seen to vein the pyrrhotite in two directions at right-angles to one another. The younger chalcoppyrite (Ca) has entered pyrrhotite in a direction parallel to the c -axis (left to right), while at right-angles to this, that is parallel to (001), pentlandite (Pe) has separated in the form of secondary exsolution lamellæ.



2. Portion of the same polished section of pyrrhotite. $\times 400$. Well-developed parting parallel to (0001) (left to right) along which serpentine and secondary carbonates have separated. In a direction at right-angles to this is a second imperfect parting into which these secondary minerals also tend to penetrate, always turning back sharply, however, to the better developed cleavage parallel to (0001). Hence the curious sutured character of serpentine and carbonate bands. Light coloured exsolution lamellæ of pentlandite are seen to have separated parallel to (0001).



wedge out in the surrounding pyrrhotite. These aggregates are from 20 to 50 μ in thickness and up to 200 μ in length (Plate XXIV.1).

The Schildpadnest pyrrhotite is perfectly normal in its optical properties such as colour, reflectivity and anisotropy. In its behaviour toward etching reagents, however, it is not; its powers of resistance being, like those of the nickeliferous pyrite, much greater than those of the pyrrhotite of other occurrences, *e.g.* Sudbury.

Pentlandite is present in two distinct forms; namely, as a primary independently-occurring mineral younger than nickeliferous pyrite and pyrrhotite, but older than chalcopyrite; and as younger secondary orientated lamellæ imbedded in pyrrhotite from which it has been derived by a process of unmixing or exsolution in the solid.

The Primary Pentlandite forms grains up to several millimetres in diameter or elongated shells rimming masses of pyrrhotite. The boundaries of the mineral toward the pyrrhotite often suggest that it has eaten into the latter and resorbed it peripherally. But there were also observed octahedral crystals of pentlandite projecting into the pyrrhotite. Pentlandite is rarely in direct contact with the silicates. Usually a thin layer of chalcopyrite intervenes.

The pentlandite is completely isotropic and is just as inert toward any of the ordinary etching reagents as is the pentlandite of Sudbury and other localities. Its reflectivity, as measured with light of different wave lengths, proved to be exactly the same as that of other specimens of pentlandite examined.

Of inclusions in the mineral there were noted, in addition to the relicts of nickeliferous pyrite already mentioned, occasional narrow lamellæ of cubanite or chalmersite. These are arranged parallel to the cubic planes of the pentlandite. They probably represent small amounts of copper sulphide, originally in isomorphous solution in the pentlandite, which became individualised as a result of unmixing in the solid.

The well-defined rectilinear octahedral cleavage cracks of the pentlandite are always occupied by thin seams of non-metallic minerals ranging from 5 to 15 μ in thickness (Plate XXII.1). We have to do here with later infiltrations of serpentine, chlorite, calcite and other decomposition products. These cleavage cracks terminate abruptly against the other

sulphides such as pyrrhotite. The same minerals, however, as previously mentioned, occur also in the cleavage cracks of the pyrrhotite.

These minerals are without doubt of hydrothermal origin and due to the activity of fugitive constituents—mainly water—released from the magma long after its consolidation.

That the big pentlandite grains are primary or, in other words, direct separations from the magma, and have not been formed by subsequent unmixing from nickeliferous pyrrhotite, appears to me to be proved by the fact that the relative amounts of the two minerals present and their textural relations are quite different from those in the ordinary platinum-poor or platinum-free nickeliferous pyrrhotite deposits.

With regard to the amounts present, reference may be made to the following compilation:—

Table showing Ratios of Pyrrhotite: Pentlandite: Chalcopyrite in the Sulphidic Ores of the Bushveld Complex.

	Vlakfontein, No. 4 Working.		Merensky Horizon.		
	I.	II. ¹	Dwarsrivier, No. 86.	Sandsloot, No. 276.	Steelpoort Park, No. 1076.
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Pyrrhotite . . .	92.4	62.3	51.2 ²	38.9 ³	39.1 ⁴
Pentlandite . . .	4.4	27.7	40.2	46.3	37.2
(Fe, Ni)S . . .	...	...	8.6	14.8	23.7
Chalcopyrite . . .	3.2	...	...	...	...

¹ Wagner, P. A. (26), p. 93.

² " " (31), p. 104.

³ Wagner, P. A. (31), p. 116.

⁴ " " (31), p. 121.

In the normal nickeliferous pyrrhotite deposits, as represented by those on Vlakfontein, No. 902, in the Rustenburg district, the ratio of pentlandite to pyrrhotite ranges from 1:15 to 1:20. J. H. L. Vogt gives similar figures for the Norwegian deposits and those for the Canadian are also similar. In the deposits on the Merensky Horizon, on the other hand, in the Lydenburg, Rustenburg and Potgietersrust districts, the ratio is roughly as 1:1. Pentlandite sometimes even preponderates over pyrrhotite. A similar ratio between the two minerals was found in the sulphide aggregates of Schildpadnest examined by me. Measurements with a planimeter proved



1. Polished section by reflected light, unetched. $\times 200$. Ore of Merensky Horizon, Schildpadnest, No. 233. Secondary pentlandite (Pe) forming brushlike aggregates of exsolution lamellae in pyrrhotite. The black lines and areas are veins of serpentine and carbonates following cleavage cracks.



2. Polished section by reflected light, unetched. $\times 200$. Ore of Merensky Horizon, Schildpadnest, No. 233. Hydrothermal serpentine zone with network of millerite (Mi) veins in pyrrhotite. At top and bottom of field, chromite (Ch) showing high relief and enclosing pyrrhotite (Py).



the proportions of pentlandite to pyrrhotite to be between 1:1 and 1:3.

With such a high concentration of nickel, pentlandite evidently crystallises direct from the magma, a conclusion that is in complete accord with the results of recent experiments by W. H. Newhouse (81). Only when the concentration is much lower does the nickel enter into solid solution in the pyrrhotite, later separating by unmixing in the solid in the form of a mesh holding grains of pyrrhotite which appear encased in thin shells of pentlandite (*maschenstruktur*), or, where the concentration of nickel is very low, as thin orientated lamellæ in the interior of the pyrrhotite (*lamellarstruktur*).¹

The *Secondary Pentlandite* occurs in the ores under description as thin orientated lamellæ enclosed in the pyrrhotite. They were described when dealing with this mineral.

Chalcopyrite.—This mineral is usually found rimming the other sulphides and separating them from the silicates. It is often seen to penetrate into the cleavages of the biotite, pyroxene and hornblende (Plate XXV). It is also found in the interior of the sulphide aggregates following the boundaries between different sulphide grains. Finally it often occurs rimming corroded relicts of nickeliferous pyrite. In all these circumstances it is evident that the chalcopyrite is the youngest or last-formed of the primary sulphides. Included in it are frequently found orientated lamellæ of *cubanite* arranged parallel to the faces of the sphenoid. Such lamellæ are very characteristic of the chalcopyrite of copper deposits formed at high temperatures.

In its physical properties the mineral is normal, colour, anisotropy and reflectivity being the same as usual. It is much twinned, and individual grains of very unequal size are intimately dovetailed. In its behaviour toward etching reagents it shows no appreciable difference from other specimens of chalcopyrite.

Unidentified Ore Mineral.—As orientated inclusions in the chalcopyrite there occurs a mineral with high reflectivity that exhibits very strong reflection-pleochroism and a very high degree of anisotropy. Further details regarding its optical behaviour are given later. It is also present in large amounts in other specimens of ore from the Merensky Horizon.

¹ Cf. Schneiderhöhn, H. (86), p. 525.

Millerite.—In places the silicates are traversed by stringer zones and a network of veins of serpentine and carbonates. These are connected with the previously described cleavage fillings in pentlandite and pyrrhotite. Where the serpentine veins approach the sulphides one generally notices at the centre of the veins minute ore stringers that, extending outward from the sulphides, are seen to branch in complex fashion and to wedge out in the sulphides (Plate XXIV.2). The thickness of the ore stringers ranges from 5 to 10 μ . The ore mineral is soft. It has about the same hardness as chalcopyrite (judging by the Light Line it is just noticeably harder). The colour is somewhat darker than that of chalcopyrite, with a more pronounced orange tint. Between crossed nicols it is strongly anisotropic, extinguishing twice. The colour in one position of maximum illumination is dark steel-blue, in the other golden yellow. Pronounced cleavages, making an angle with the positions in which it extinguishes, are often visible. The texture of the stringers is granular and pinnate. In addition to its occurrence as narrow stringers, the mineral forms big homogeneous plates with distinct cleavage cracks in the sulphide aggregates in the neighbourhood of the serpentine veins, already mentioned. It is clearly younger than the sulphides with which it is here in contact.

All its properties point to its being *millerite* NiS (W. Forke, 68). The mineral is apparently an alteration product of pentlandite, its formation being connected in some way with that of the serpentine which here has clearly nothing to do with normal surface weathering.

The Chrome Band.

This consists predominantly of grains of chromite which range up to several millimetres in diameter. For the most part they are rounded, but in places they show indications of octahedral outlines. They are imbedded in a groundmass of diallage, bronzite and plagioclase which enclose the chromite grains poikilitically. Small patches of sulphide occur in the interstices between the chromite grains (Plates XXVI.1 and 2).

The chromite grains are free from sulphide inclusions, but here and there show enclosures of an anisotropic mineral of approximately equal hardness and somewhat lighter colour.



1. Polished section by reflected light, unetched. $\times 30$. Ore-bearing felspathic harzburgite, Schildpadnest, No. 233. Tongue of sulphides in diallage (black). Nickeliferous pyrite (Ni) occurs as replacement residuals in pyrrhotite (Py), while chalcopyrite (Ca), the latest formed sulphide, borders these minerals. The marginal penetration of diallage by chalcopyrite is well shown.



2. Portion of the same polished section. $\times 80$. Shows details of the penetration of diallage by chalcopyrite.



It probably represents specularite formed by unmixing in the solid. Apart from this the chromite is perfectly homogeneous. The intergranular sulphide bodies are identical with those in the associated rocks. The "Chrome Band" is sharply defined from the overlying Merensky "Reef" and the underlying felspathic harzburgite (Plate XXVI.1).

I. (2) The Ores of Vlakfontein, No. 902.

While these occurrences, situated 30 miles north-west of Rustenburg, are poor in platinum metals and belong to the category of the nickeliferous pyrrhotite deposits, they may be included here for the sake of comparison. Good fresh specimens of the several types of ore and of the rocks enclosing it were collected and handed over to me by Professor E. Kaiser, of Munich. I am also indebted for specimens to Professor H. Lotz, of Berlin.

Sulphides occur here both in bronzitite and in a pyroxenitic olivine-norite. These rocks are described in detail by P. A. Wagner in his comprehensive memoir on these deposits (26). The mineragraphy of the ores has also been treated by Wagner.

According to the degree of concentration of the sulphides in the igneous rocks, three types of ore are discriminated, namely:

- (1) Disseminated or spotted ore.
- (2) Mottled or poikilitic ore.
- (3) Massive ore.

In type (1) the sulphides occur in the intergranular spaces and only rarely along the contacts between silicate grains. The primary silicates do not, as a rule, border directly on the sulphides, a reaction rim being generally developed between them. This usually consists of hornblende developed from bronzite in the case of bronzitite and from diallage in the case of pyroxenitic olivine-norite; the hornblende being in crystallographic orientation with these minerals. More rarely the reaction rims consist of biotite. These reaction minerals are intimately intergrown and interfingered with the sulphides on the side of the reaction rims in contact with them (Plate XXVII.2). To this phenomenon, which has been described and figured (75 and 90) in connection with all magmatic nickeliferous pyrrhotite deposits, I shall refer again in the section dealing with the genesis of these ores.

In ore-types 2 and 3, where sulphides preponderate and the silicates occur in rounded grains floating, as it were, in the sulphides, these reaction rims are less frequently developed.

The sulphide aggregates in the Vlakfontein ores consist mainly of pentlandite, pyrrhotite and chalcopyrite. Pyrite and nickeliferous pyrite are not present in the specimens examined. Nor did I come across: (*a*) the hard white isotropic sulphide mineral mentioned by Wagner and provisionally identified by him as *polydymite*, or (*b*) a mineral with the properties of "violarite" as described by W. Lindgren and A. F. Buddington (66).

On the other hand there occurs in considerable amounts, enclosed in the pentlandite of Vlakfontein, the same *unidentified opaque ore mineral* which is also frequently present in the sulphide ores of the Merensky Horizon, and has been mentioned in connection with Schildpadnest. It has so far not been described in detail by anyone, though Ramdohr (86) refers to it incidentally. It is more fully dealt with in the appendix to this section.

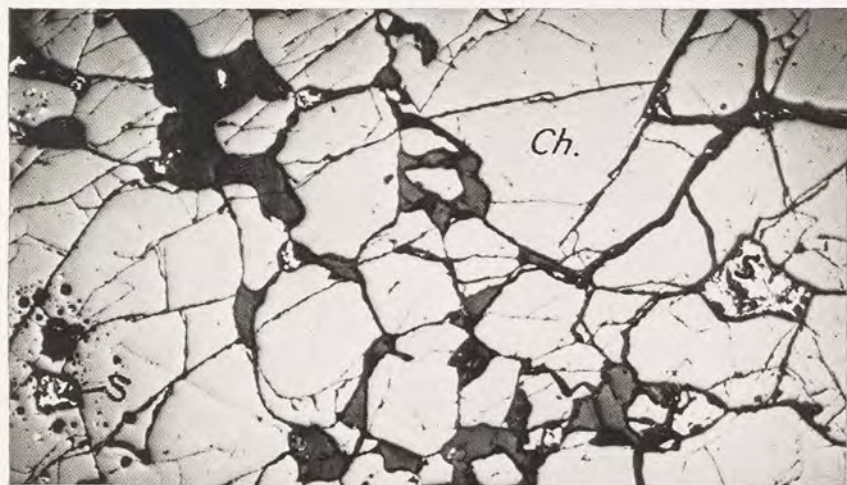
The Vlakfontein *pentlandite* shows certain peculiarities as compared with ordinary pentlandite. It is seen, even under magnification as low as 500, to be inhomogeneous and to consist of two components showing a just perceptible difference in colour, the normal pentlandite colour being a little darker in one of the components than in the other. Under this magnification the two minerals form an irresolvable network with one another. They both have exactly the same hardness and the same etching properties as those of ordinary pentlandite, and they are both completely isotropic.

The *pyrrhotite* forms unusually big grains often several centimetres across. It is characterised by its well-defined basal cleavage. Coarse twin-lamellæ, inclined at an angle to the basal pinacoid, are sometimes in evidence within the grains. Exsolution "brushes" of secondary pentlandite (also referred to by Wagner) are of frequent occurrence.

Chalcopyrite is again the last-formed sulphide. It occurs peripherally to the other sulphides and is found penetrating them along cleavage cracks. It is also often found as orientated parallel lamellæ occupying the cleavages of the reaction minerals hornblende and biotite. Lamellæ of cubanite (due to unmixing) are of frequent occurrence in the mineral in their usual orientation.

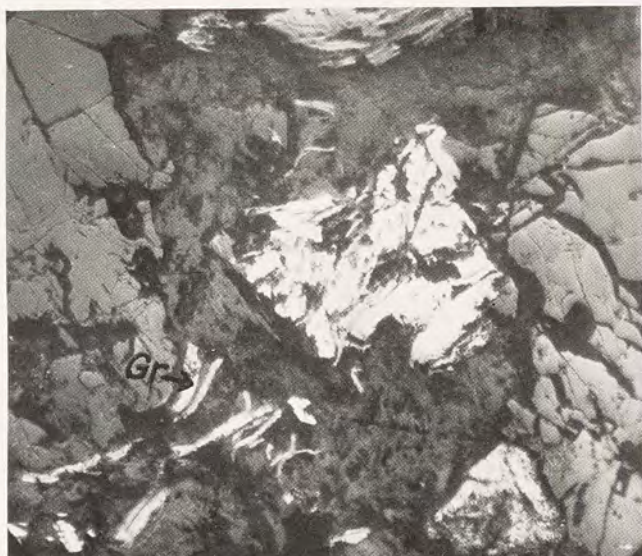


1. Polished section by reflected light, unetched. $\times 10$. Ore of Merensky Horizon, Schildpadnest, No. 233. Contact of Chrome Band (above) with felspathic harzburgite (below). Isolated sulphide droplets (white) are in evidence in the felspathic harzburgite.

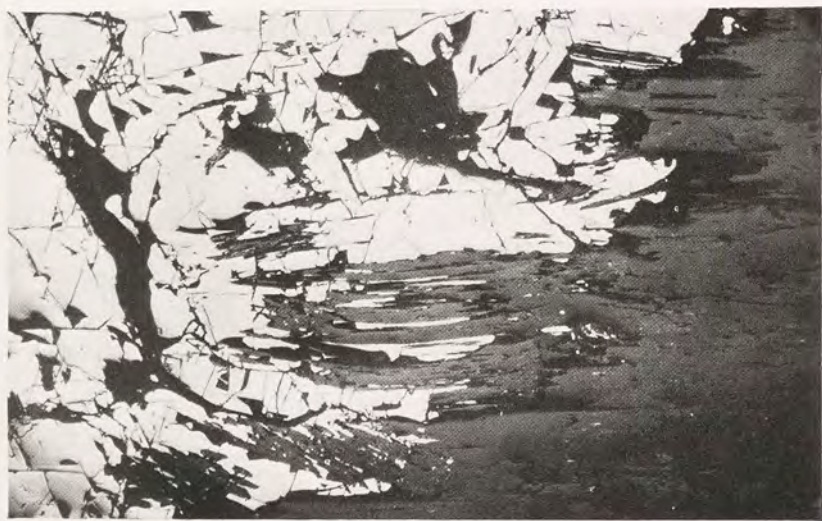


2. Portion of the same polished section. $\times 40$. Illustrates constitution of Chrome Band. Chromite (Ch), sulphides (S), diallage (black).





1. Polished section by reflected light. $\times 100$. Ore of Vlakfontein, No. 902, Rustenburg district. Reaction minerals in disseminated ore. At centre of field confused fibrous aggregate of hornblende and biotite (dark grey and rough-looking) enclosing bent lamellæ of graphite (Gr) and grains of pyrrhotite (white); on right and left, bronzite (smooth and grey in colour).



2. Polished section by reflected light. $\times 40$. Ore of central sector, Sandsloot, No. 276, at depth of 30 m. (Reuning Collection, No. 11.) Textural relations of sulphides and silicates in coarse-grained feldspathic pyroxenite. Left, pentlandite (white) showing octahedral cleavage. On right, diallage (black) passing outward into crystallographically orientated hornblende. The hornblende, which is intimately intergrown with pentlandite, is of the nature of a reaction mineral formed along the contact of the diallage and the sulphides.



These sulphides are often accompanied in the interstices between the silicates by idiomorphic plates of hornblende and biotite. Fibrous and confusedly fibrous aggregates of these silicates, themselves enclosing specks of sulphides, are found enclosed in the sulphides. Not infrequently one also finds enclosed in the sulphides *graphite* in bent and wavy lamellæ (Plate XXVII.1). To this fact Wagner (26) has also called attention.

Appendix—The unidentified opaque nickel-iron ore mineral showing strong reflection-pleochroism found enclosed in pentlandite and chalcopyrite.—Reference has already several times been made to this mineral, and it is also present in most of the ores to be described in the following pages. It has the following mineragraphic properties:—

<i>Capacity for taking polish</i>	Good, like chalcopyrite.
<i>Hardness</i>	Exactly the same as pentlandite (determined by means of the Light Line; cf. Schneiderhöhn (85), p. 85).
<i>Cleavage</i>	Absent.
<i>Reflectivity</i>	Fairly good, like chalcopyrite.
<i>Reflection-Pleochroism</i> .	As observed with lower nicol exceptionally strong, stronger than that shown by any other opaque mineral. The colour in one direction is bright yellow, almost exactly like chalcopyrite, but with a pink tint; in the other direction, at right-angles to this, dark-grey, almost exactly like zinc blende, and apparently darker than chromite.

In polarised light between crossed nicols the mineral also shows the most pronounced anisotropy of any opaque mineral with which I am acquainted, even more pronounced than that of graphite and covellite. It extinguishes twice and shows two almost equal positions of maximum illumination in between, in which it appears bright pure white. These become evident even with weak illumination when no other mineral shows any anisotropic effects between crossed nicols.

Using oil immersion the anisotropic and reflection-pleochroism effects are considerably augmented.

Etching Properties:—

HCl conc.		neg.
HNO ₃ conc.		„
Aqua regia conc.		„

It is only attacked under strongly oxidising conditions by nascent chlorine, generated by dropping solid potassium chlorate into concentrated hydrochloric acid, into which the polished surface is then immediately dipped. Under this treatment the surface of the mineral becomes rough and dull, without, however, any good etch structure being brought out.

Twin lamellae, zonal structure, deformations and inclusions were not observed either using one or both nicols or after etching.

Occurrence.—The mineral has so far been observed by me mainly in pentlandite and more rarely in chalcopyrite. In chalcopyrite it occurs as minute irregular branching bodies up to several thousandths of a millimetre in length which, in any individual chalcopyrite crystal, show the same orientation. In pentlandite it occurs in bigger grains up to 50μ across. Here too are found irregular branching bodies. As a rule, however, these show sharp boundaries parallel to the octahedral planes of the pentlandite. In other directions they interfinger with the pentlandite and fray out in it. In all circumstances the individual grains within a homogeneous pentlandite grain show the same crystallographic orientation, the direction in which they extinguish between crossed nicols being parallel to the cube-planes of the pentlandite. Frequently one sees within a single pentlandite crystal dozens of minute grains of the mineral lying close together.

While the manner of occurrence of the mineral within the pentlandite and chalcopyrite has thus a certain similarity with that commonly associated with substances formed by unmixing in the solid, the shape of the grains, on the other hand, is different from the shape commonly assumed by those formed by unmixing, as will be seen by reference to Plates XXX.I. and XXXII.I.

The properties of the mineral agree with those of no known mineral. To get some idea of its composition, an arc spectrum was obtained in a quartz spectrograph, with ultra-violet light, by my assistant, H. Moritz, from minute shavings bored out of polished sections of the mineral by means of a micro-borer to be presently described. The spectrographic analysis, given on page 236, shows that we have to do with a nickel-iron ore rich in iron, which contains, in addition, appreciable amounts of cobalt and palladium, and traces of iridium, antimony, gold and silver. Sulphur and arsenic were not tested for.

II. Lydenburg District.

(1) *The Ore of the Merensky Horizon on Dwarsrivier, No. 86.*

Six specimens of pyroxenitic diallage-norite (Merensky "Reef") sent me in 1925 by P. A. Wagner were examined. They correspond with the material described by Wagner (31).

The sulphides lie in the interspaces between the silicates. Reaction rims of hornblende and biotite occur between the sulphides and primary silicates, but are not very well developed.

Among the sulphides *chalcopyrite* preponderates in the material examined by me. It is, as usual, the latest of the sulphides to be formed. It generally occupies with pyrrhotite the centre of the sulphide aggregates, which are rimmed by a wreath of pentlandite octahedra. The pyrrhotite here shows no twin lamellæ or cleavage parallel to (0001). Here and there granules of the unknown opaque mineral, described above, were observed enclosed in chalcopyrite. Inclusions of graphite are not uncommon in the sulphides.

(2) *The Ores of Mooihoek, No. 147.*

Dr Reuning sent me in 1925 a suite of specimens from this farm including anorthosite, norite, hortonolite-dunite and its several differentiates. Platiniferous sulphidic ores were especially well developed in some vein- and schlier-like chromite-rich differentiated bodies occurring in the footwall (? P. A. W.) norite. They contain much hornblende and serpentine.

The sulphides form isolated patches, generally showing at the middle bigger grains of pyrrhotite. The pyrrhotite here always exhibits a fine twinning with bent and splayed twin lamellæ, which are probably of the nature of "alteration twins." It is often surrounded by a fringe of pentlandite crystals, extraordinarily rich in orientated inclusions of the unidentified strongly pleochroic opaque mineral. This occurs in the pentlandite in the manner previously described (Plate XXXII.1). Skeletal graphite crystals are also common in the pentlandite. Chalcopyrite is rarer and occurs, as a rule, in thin lamellæ occupying the cleavages of the hornblende. Serpentine is accompanied by the same strongly anisotropic ore-mineral as was noted in the Schildpadnest ore, and identified as *millerite*. Here too it forms irregular veins and stringers in the serpentine, but in addition occurs in idiomorphic prisms and crystal groups in the serpentine.

III. Potgietersrust District.

On the Potgietersrust fields, as has been shown, there are represented three types of platinum deposits associated with sulphide-bearing rocks, namely:

- (1) Platinum - bearing sulphides in normal "liquid-magmatic" basic intrusive rocks (felspathic pyroxenites, norites and pyroxenites).
- (2) Platinum-bearing sulphides with sperrylite, and other platinum ores, in pegmatitic veins and lenses.
- (3) Platinum-bearing sulphides with sperrylite and other platinum ores in lime-silicate rocks developed at the contact of the norite and the underlying dolomite.

The mineragraphic examination of the ores proves that the composition and association of the sulphides in the three types of deposit are different and that the manner of occurrence of the platinum metals in them is also different.

(1) *Platinum-Bearing Basic Intrusive Rocks.*

Here belong the following specimens from the collection of Dr E. Reuning.¹

- No. 11. Very coarse-grained pyroxenite containing about 5 gm. of platinum metals per ton; Sandsloot Central, 100-ft. level.
- No. 12. Medium coarse-grained pyroxenite containing from 3 to 4 gm. of platinum per ton; Sandsloot Central, 100-ft. level.
- No. 13. Medium-grained Merensky "Reef" containing 2 to 3 gm. of platinum per ton; Zwartfontein Central, cross-cut west of shaft, 100-ft. level.

These specimens contained the most sulphides. Specimens 4 to 10 and 13 to 15 of Reuning's collection are norites of

¹ Dr Reuning has very liberally presented the mineralogical institutes of various German and Swiss universities with fine suites of specimens of the platinum-bearing and associated rocks of the Potgietersrust fields. The numbers given by him to these specimens correspond with those in his paper (59), and also with those in the following descriptions. Apart from this collection, I am personally indebted to Dr Reuning for a large number of valuable specimens of platinum-bearing rocks and concentrates from Potgietersrust and other localities.



1. Polished section by reflected light. $\times 100$. Ore of central section, Zwartfontein, No. 121, Potgietersrust district. Cross-cut to west from Shaft No. 3 at depth of 30 m. (Reuning Collection, No. 13.) Interstitial sulphide patch in diallage (dark grey) of medium-grained felspathic pyroxenite. The sulphide patch consists of pentlandite (white) intergrown with reaction biotite (B), in small angular plates. In lower left-hand quadrant, biotite with oriented inclusions of chalcopyrite (Ca).



2. Polished section by reflected light. $\times 100$. Ore of same locality in which chalcopyrite (white) occurs in crystallographic intergrowth with labradorite (La), together with reaction biotite (pale grey). At top of field on right, diallage (Di).



varying grain and composition, and chromite and titaniferous magnetite, all of which contain only traces of sulphides.

In the felspathic pyroxenites, Nos. 11 to 13, the sulphides are again found in the interstices between the silicates. These are altered at the contacts with the sulphides to *reaction rims* of hornblende and biotite in parallel orientation with the minerals from which they have been formed. These minerals also occur completely enclosed in the sulphides in idiomorphic plates (Plates XXVII.2 and XXVIII.1). Sulphide droplets and orientated lamellæ of included sulphides—mainly chalcopyrite—are also found, usually in the outermost parts of the silicate grains. Such lamellæ are not found, as a rule, in the unaltered silicates, but occasionally grains of labradorite, that are strongly impregnated with sulphides and interspersed with orientated mica plates, are seen to enclose similarly orientated lamellæ of chalcopyrite (Plate XXVIII.2).

Pentlandite is the most common of the sulphides and in the coarse pyroxenite it is actually the predominant mineral, pyrrhotite being here almost entirely absent. The pentlandite is always coarsely crystalline, the individual crystals being up to several millimetres across. The pentlandite in itself is perfectly homogeneous. Foreign inclusions, however, are of common occurrence in it. These are mainly of hornblende and biotite in plates and idiomorphic crystals. Here and there exsolution laths of pyrrhotite are in evidence. There were also frequently noted inclusions of the previously described strongly pleochroic unidentified opaque ore mineral. This is often intergrown here with graphite. One sometimes notices that graphite stringers in pentlandite, when followed, pass longitudinally into stringers of this mineral.

Graphite also occurs independently as stringers and skeletal crystals in the pentlandite. Finally, there are present on the octahedral faces of pentlandite crystals in the medium coarse-grained pyroxenite, No. 12, very fine lamellæ of a transparent mineral, which is probably serpentine (Plate XXIX.1).

Pyrrhotite plays a subordinate role in these pyroxenitic rocks. Only in the medium coarse-grained pyroxenite is it more abundant.

Chalcopyrite again forms last among the sulphides and veins all the others. It frequently occurs along the contact of

the silicates with the pentlandite, and also in droplets and lamellæ enclosed in the secondarily formed hornblende and biotite.

(2) *Platinum-Bearing Pegmatitic Rocks.*

Specimen No. 21 of Reuning's collection is a pegmatite, with true graphic texture, from the pneumalolytic contact zones¹ of Tweefontein containing microscopic sperrylite and stibiopalladinite.

I also received from Dr Reuning concentrates obtained from similar pegmatite veins in the banded ironstones overlying the dolomite on Tweefontein.

The specimen of platinum-bearing pegmatite is derived from the oxidised zone, and is strongly impregnated along cracks traversing the coarsely crystalline silicates (mainly orthoclase), with malachite and limonite. A great part of the sulphides are, however, still well preserved and can be effectively studied under the microscope.

The following ore minerals are present: pyrrhotite, chalcopyrite, sperrylite and palladium antimonide (stibiopalladinite). Pentlandite was not observed in the samples examined.

Pyrrhotite is the predominant sulphide. It forms individuals up to several millimetres across which are perfectly homogeneous without any kind of twin lamellation. They form the long winding and branching individuals and tube-like bodies between the silicates, and are in part in graphic intergrowth with the latter. At the tips of the tube-like bodies and patches of chalcopyrite, which in the samples examined has generally been altered to malachite or limonite, isolated rhombic dodecahedra of sperrylite are enclosed in the pyrrhotite bands. The sperrylite is distinctly earlier than the pyrrhotite which penetrates it along cracks and has in places eaten into the peripheries of the crystals (Plate XXIX.2).

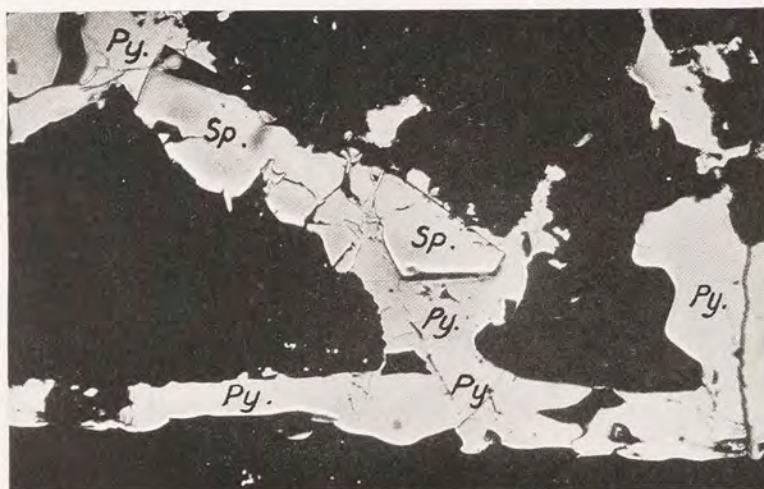
More rarely there were noted irregular grains of the palladium antimonide.

The concentrates obtained from pegmatite veins in the banded ironstones are treated in the section on the mineralogy of the platinum minerals.

¹ Pneumalolytic contact zone is an admittedly inadequate translation of Professor Schneiderhöhn's far more expressive *pegmatitische Durchgasungszonen*.



1. Polished section by reflected light. $\times 100$. Ore of central section, Sandsloot, No. 276, Potgietersrust district, at depth of 30 m. (Reuning Collection, No. 12.) Microtexture of pentlandite in medium-grained feldspathic pyroxenite. Thin lamellae of what is taken to be secondary serpentine have separated along the octahedral planes.



2. Polished section by reflected light. $\times 100$. Pegmatite from pneumatolytic contact zone on Tweefontein, No. 1033, Potgietersrust. (Reuning Collection, No. 21.) The graphic intergrowth is between orthoclase (black) and pyrrhotite (Py), the pyrrhotite enclosing crystals and corroded grains of sperryllite (Sp).



(3) *Platinum-Bearing Lime-Silicate Rocks.*

Here belong samples Nos. 16 and 17 of the Reuning collection.

No. 16.—Blue-black serpentinitised lime-silicate rock (metamorphosed dolomite), containing sulphides and from 6 to 8 gm. of platinum metals per ton. It occurs directly in contact with ore-bearing pyroxenite in the Zwartfontein South Sector.

No. 17.—Coarse-grained pyroxene rock (completely metamorphosed dolomite), containing sulphides and from 8 to 10 gm. of platinum metals per ton. Specimen taken in the footwall of the cross-cut at a depth of 90 feet toward the west, from No. 3 shaft, Zwartfontein Central.

In these rocks the sulphides occur in angular, ragged, and in part lamellar and often branching intergrowths with platy and easily cleaved silicates such as diopside, hornblende and biotite. The size of the individual sulphide bodies is extraordinarily variable and the degree of intergrowth with the silicates very intimate, much more so than in the igneous rocks.

Pentlandite and *Pyrrhotite* are present in approximately equal proportions; *chalcopyrite* is less abundant. *Cubanite* lamellæ are of very common occurrence in the *chalcopyrite*, and *cubanite* also occurs here as an independent mineral not bound up with *chalcopyrite*, a mode of occurrence that hitherto had not been definitely known (Ramdohr 84).¹

In addition to the sulphides, *sperrylite*, the palladium antimonide and native gold are present.

The *pentlandite* crystals are here again very big, ranging up to several millimetres across. A colourless silicate, probably *serpentine*, is often seen to have separated out in the well-defined cleavages of the mineral (Plate XXX.1). It also encloses numerous and large individuals of the unidentified strongly pleochroic opaque mineral (Plate XXX.1). Some of its crystal faces parallel the octahedral planes of the *pentlandite*; along other contacts it is intimately intertwined with that mineral. Finally, reference must be made to the occurrence

¹ It also occurs independently of *chalcopyrite* in the dunites of the Lydenburg district and in the Uralian dunites (P. A. W.).

in the pentlandite of numerous enclosures of graphite, mostly in the form of irregular skeleton crystals (Plate XXX.1).



FIG. 31.—Coarse-Grained Contact-Silicate - Rock, Zwartfontein Central, Potgietersrust (No. 17, Reuning Collection).

- | | |
|-----------------------|------------------|
| 1. Stibiopalladinite. | 3. Chalcopyrite. |
| 2. Gold. | 4. Chromite. |
| 5. Hornblende. | |

(Drawn from a polished section by means of a sketching ocular.)

Pyrrhotite and *Chalcopyrite* do not present any features of special interest. *Cubanite* occurs as exsolution lamellæ lying parallel to the $\{111\}$ planes of the chalcopyrite; also, as previously stated, independently of that mineral, in veins up to 0.5 cm. wide, mostly in pentlandite. These veins are seen to branch laterally in the pentlandite and are clearly younger than that mineral. One frequently sees that pentlandite has been replaced by cubanite (Plate XXX.2). Cubanite in these circumstances takes the place of chalcopyrite which elsewhere occurs in the same manner: in narrow stringers presenting evidence of having replaced pentlandite. In places I noted small lamellæ of chalcopyrite lying parallel to $\{111\}$ in the cubanite, so that in these particular occurrences the normal relations between the two minerals are reversed. The twin mesh structure mentioned by Ramdohr and noted by me in many other occurrences of the mineral was not observed. In other respects it is identical as to optical and chemical properties with the cubanite of other localities. The reflectivity of

the mineral was carefully measured and found to be exactly the same as usual.



1. Polished section by reflected light. $\times 200$. Microtexture of pentlandite in blue-black serpentinised silicated dolomite, South Sector, Zwartfontein, No. 121, Potgietersrust district. (Reuning Collection, No. 16.) Serpentine in extremely thin lamellæ occupies the octahedral cleavages. Isolated orientated grains and lamellæ of the unidentified strongly pleochroic opaque nickel-iron mineral (U) are enclosed in the pentlandite. Skeleton crystal of graphite (Gr) is seen on left.



2. Polished section of ore of same locality (Reuning Collection, No. 16) of the primary cubanite veining pentlandite (greyish-white) showing octahedral cleavage.



Sperrylite, stibiopalladinite and native gold are found as rarities enclosed in the sulphides.

Sperrylite occurs in pentagonal dodecahedra imbedded in sulphide veins composed of pentlandite or pyrrhotite, by which it has in places been corroded at the margins (Plate XXXI.1).

Small grains of *native gold* were noted too. They are always found in the sulphide lamellæ occupying the cleavages of hornblende. They are accompanied by minute grains of chromite, stibiopalladinite and chalcopyrite. The manner of occurrence and textural relations of the several minerals are shown in Fig. 31, which was drawn to scale with the aid of the special sketching ocular of the firm of E. Leitz, Wetzlar.

The degree of intergrowth of the sulphides with one another and with the silicates is, as already stated, far more intimate than in the pyroxenites. The silicates are much more inter-fingered than the sulphides along their margins, and inclusions of the sulphides in the silicates are far more numerous. One frequently finds long rows of minute chromite octahedra following the silicate contacts, the octahedral corners of the crystals projecting into the adjacent sulphides. Chromite also occurs in very thin stringers and individual grains within the silicates and sulphides.

The chromite stringers are generally accompanied by serpentine. Serpentine veins are also often found intersecting the sulphides, usually along their cleavage planes (Plate XXXI.2), but sometimes irregularly and at random.

Graphite, which is by no means uncommon in these ores, also enters into the composition of the stringers, cutting the silicates and more particularly the sulphides.

IV. Mineragraphical Observations on the Occurrence of the Platinum Group Metals in the Nickel-Pyrrhotite Bearing Rocks of the Bushveld Complex.

(1) *Minerals of the Platinum Group Metals.*

The mineralogy of the platinum group metals has already been dealt with in Chapter II. None of the native metals or of their natural alloys listed have so far been observed by me in any of the fresh unweathered sulphide-bearing igneous rocks examined. Had they been present they could hardly have escaped detection as, owing to their high reflectivity,

their recognition in polished sections is very easy. They are, moreover, soft and ductile and for this reason their polished surfaces generally show characteristic scratches. Even under the highest powers of magnification not so much as a trace of a grain of what might be platinum was observed.

Sperrylite, however, which had already been discovered by Wells as early as 1889 in the nickeliferous pyrrhotite deposits of Sudbury, was identified in the Bushveld platinum deposits soon after the discovery of the Merensky Horizon.

More recently, two other naturally occurring compounds of the platinum metals have been discovered. They are a platinum sulph-arsenide, first identified by R. A. Cooper, which P. A. Wagner has named *cooperite*, and a palladium antimonide discovered by H. R. Adam, for which Wagner has proposed the name *stibiopalladinite*.

Samples of these two minerals were sent me by Dr Wagner. To Dr E. Reuning I am indebted for crystals of sperrylite from the pegmatite on Tweefontein¹ and for samples of concentrates from Tweefontein and Zwartfontein South and Central.

(2) *Mineragraphy of Sperrylite, Cooperite and Stibiopalladinite.*²

Cooperite.—The material submitted to me had been obtained by treating a gravity concentrate from the Klipfontein-Kroondal Mine in the Rustenburg district, with *aqua regia*. Cooperite itself is, as already stated, insoluble in *aqua regia*. The grains and crystal fragments of the mineral present were up to 0.1 mm. in diameter. They are generally prismatic in habit like the usual combination of arsenopyrite, but sometimes also equidimensional. The angle between the crystal faces present is approximately 90 degrees. On most of the isometric pieces there was apparent in polarised light a twinning edge. The two halves of the twin crystal extinguish at different angles but always symmetrically. The angle between the extinction positions of the two halves fluctuates

¹ These were found to be accompanied by small grains of stibiopalladinite.

² Professor Schneiderhöhn prefaced this section with a table giving the mineragraphic properties of the three minerals. The data contained in this table have been incorporated in that already presented in Chapter II., page 18 (P. A. W.).



1. Polished section by reflected light. $\times 100$. Coarse-grained contact lime-silicate rock, Central Sector, Zwartfontein, No. 121, Potgietersrust, from footwall cross-cut toward west from Shaft No. 3 at a depth of 30 m. (Reuning Collection, No. 17.) Sulphides and sperrylite between contact silicates [biotite and hornblende with serpentine veins (black)], pyrrhotite (Py), chalcopyrite (Ca), sperrylite crystal (white on left).



2. Polished section. $\times 50$. Interstitial sulphide aggregate in coarse contact silicate rock, central sector, Zwartfontein, No. 121, Potgietersrust. On left, pentlandite (Pe), the octahedral cleavages of which are occupied by secondary serpentine; pyrrhotite (Py) and chalcopyrite (Ca) above, and on right, are intimately intergrown.



between 90 degrees and 120 degrees. The extinction positions were always clearly defined and easily seen. In the positions of maximum illumination the colours are grey-pink and grey-green. The anisotropy may thus be described as weak. More rarely there were observed twinned grains with step-like edges and polysynthetic lamellæ (Fig. 32).

By treatment with hot concentrated *aqua regia* the cooperite crystals were slightly etched, elongated asymmetrical etch-figures extending parallel with a crystal edge being formed. This would not be in accord with rhombic symmetry. The observations made, however, did not suffice to enable definite conclusions to be drawn in regard to the class of the symmetry.

They suggest that cooperite is rhombic, perhaps rhombic-hemimorphic, and that it is crystallographically closely related to arsenopyrite,¹ which is also indicated by its chemical composition. The twinning in the case of arsenopyrite is probably parallel to $\{110\}$. If that be so the facial angle $\{110\}:\{\bar{1}10\}$ would approximate to 90 degrees.

The *Palladium antimonide*, for which Wagner has proposed the name *stibiopalladinite*, in its mineragraphic properties most closely resembles sperrylite. Only when the two minerals are seen lying side by side in a polished section can the palladium mineral be picked out by its slight yellowish-pink tint. Both minerals are isotropic in unetched polished sections, and both show high reflectivity. There is, however, as already indicated by Dr Wagner, a considerable difference in their hardness values.

Etching by means of nascent chlorine affords an excellent means of distinguishing them. *Aqua regia* attacks the palladium mineral strongly, the polished sections becoming rough, dull and assuming a yellowish-brown colour. The internal structure is, however, only feebly revealed by this means. It is brought out much better by dipping a polished section for a few seconds into concentrated hydrochloric acid into which a knife-point-full

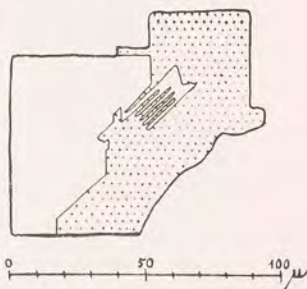


FIG. 32.—Twinned Crystal of Cooperite drawn from a polished section by means of a sketching ocular.

¹ Dr P. A. Wagner had previously suggested this to me in a letter written in September 1928.

of potassium chlorate has shortly before been dropped, so as to produce a violent evolution of chlorine. After from three to five seconds the grain boundaries of the individual crystals become clearly visible, and, according to the direction in which the section is cut, show different degrees of etching and different shades of yellow and brown. Sperrylite and cooperite are entirely unaffected by this treatment.

The etching brings out in the palladium antimonide grains a peculiar internal radial structure which, magnified 400-fold, is well shown in Plate XXXII.2. One sees rectangular short columnar cross-sections which cross and re-cross, sometimes intersecting one another at right-angles. They apparently radiate outward from the grain contacts, suggesting that the palladium antimonide crystals grow outward from the walls of small drusy cavities. The etched polished surfaces show very weak anisotropy, but, owing to the smallness of the grains, it was impossible to decide whether we have to do here with true anisotropy or an effect due to the surface relief caused by etching. The columnar habit, as revealed by etching, is really a stronger argument against the assumption that the mineral may belong to the isometric system.

(3) *Table of Absolute Reflectivities.*

To assist in the discrimination of the sulphides and platinum group metals, there is presented hereunder in tabular form the only microscopic constants in regard to these minerals so

Mineral.	Locality.	Absolute Reflectivity.		
		Green Light.	Orange Light.	Red Light.
		Per cent.	Per cent.	Per cent.
Platinum . . .	Nijni Tagilsky	65	65	65
" . . .	North Carolina, U.S.A.	65	65	65
Iridosmium . . .	Syssersk, Urals	59	54	53
Stibiopalladinite . . .	Twefontein, Potgietersrust	56	56	56
" . . .	" "	57	57	57
Sperrylite . . .	" "	54	53	51
" . . .	" "	53	51	51
" . . .	Vermilion Mine, Canada	53	53	51
Pentlandite . . .	All localities	49	48	45
Laurite . . .	Borneo	42	40	37
Chalcopyrite . . .	All localities	39	39	39
Pyrrhotite . . .	"	37	37	36
Cooperite . . .	Klipfontein-Kroondal Mine, Rustenburg	37	37	36

PLATE XXXII



1. Polished section by reflected polarised light. Crossed Nicols $\times 200$. Ore of footwall norite (?) Mooihoek, No. 147, Lydenburg district. Unidentified strongly anisotropic nickel-iron ore mineral (white) forming orientated inclusions in pentlandite (dark grey) from which it has probably been derived by unmixing in the solid.



2. Polished section by reflected light after etching for five seconds with concentrated HCl-KClO_3 , $\times 400$. Illustrates microstructure of stibiopalladinite of Tweefontein, No. 1033, Potgietersrust district.



far accurately measured, namely, their absolute reflectivities. They were determined by Mr H. Frick¹ by means of the reflection-photometer ocular designed by me (88).

(4) *The Manner of Occurrence of the Platinum Group Metals in the Rocks and Concentrates Examined.*

It has already been pointed out that in the numerous samples examined of the various types of ore entering into the constitution of the Merensky Horizon in the Rustenburg, Lydenburg and Potgietersrust districts I did not come across so much as a trace of a platinum or palladium mineral under the microscope, notwithstanding that a large number of excellent polished sections were submitted to the closest scrutiny, using the highest powers of magnification with oil-immersion objectives.

In the *pegmatitic* ores of Tweefontein, on the other hand, and in the *contact metamorphic lime-silicate rocks* of Zwartfontein, sperrylite and the palladium antimonide were noted in all the polished sections prepared.

In the *concentrates* examined² the following platinum minerals were identified:—

No. 23, Reuning Collection.—This is a concentrate obtained from the platinum-bearing pegmatites in the banded ironstones of Tweefontein, No. 1033. It contains, in addition to magnetite, titanomagnetite and chromite, considerable amounts of sperrylite and stibiopalladinite, the two minerals being present in roughly equal proportions.

Two samples of concentrates from the felspathic pyroxenites of Zwartfontein were examined, namely:—

A sulphidic concentrate from the treatment of fresh unweathered rocks as exposed at a depth of 30 metres.

¹ The data are quoted from the unpublished doctorate thesis of Mr Frick.

² Very good polished surfaces of concentrates can be obtained by imbedding them in the cements used by dentists and then grinding and polishing them in the ordinary way. The hardest cement obtainable in the trade should be employed. Sealing-wax recommended in my book (85, p. 61) is suitable for soft minerals but is not suitable for harder minerals as they stand out in too great relief on being polished.

These contain 1510 gm. per ton of platinum metals of which platinum represents 820 gm. (No. 24, Reuning Collection).

The concentrate from the treatment of the completely decomposed and disintegrated pyroxenite (No. 22 and No. 10, Reuning Collection).

In the *sulphide concentrate* I did not succeed in finding a single particle of a platinum mineral. It consists for the most part of grains of pentlandite accompanied by subordinate amounts of pyrrhotite and cubanite. Chalcopyrite is less abundant. The platinum metals are here evidently contained in the sulphides. The examination of these concentrates thus confirms the result of the examination of polished sections of these rocks.

The *concentrate derived from the decomposed pyroxenite*.—This does not contain a single sulphide grain. All the sulphides have been completely oxidised and dissolved.

Among the non-decomposed minerals such as magnetite, titanomagnetite and chromite one finds in the concentrate fairly numerous grains of *native platinum*. These consist of platinum exhibiting a concentric zonal structure and enclosing a core of metallic *palladium*. Quite a number of grains of native gold were also noticed, and in several instances small pieces of *wire gold* were found sticking to grains of native platinum. The manner of occurrence of the precious metals proves clearly that they are here of secondary or supergene origin. They were evidently released as a result of the decomposition of the sulphides and then separated out in the oxidised zone in the native state as minute concretions.

The results of the mineragraphic examination of the ores and concentrates may thus be summarised as follows:—

- (a) In the pegmatitic and contact metamorphic deposits the platinum metals are present as sperrylite and palladium antimonide.
- (b) In the unweathered platinum-bearing intrusive rocks no platinum minerals could be identified.¹

¹ Professor Schneiderhöhn's conclusions must be taken to refer only to the primary ores of the Potgietersrust district which he examined. In the Rustenburg district cooperite has been definitely identified in the sulphide ore, the mineral, as already stated, being sometimes visible in hand specimens (P. A. W.).

- (c) The weathered intrusive rocks from above water-level contain platinum, palladium and gold in the native state, in a form that leaves no doubt as to their secondary derivation in the oxidised zone from the weathering of platinum-bearing sulphides.

As the platinum and sulphide-bearing intrusive rocks constitute the most important type of occurrence, it is very important to know with what minerals in them the platinum metals are associated and in what amounts they are contained in them. Having regard to the above findings, it was clear that this problem could not be solved by microscopic work but only chemically. In view of the intimate intergrowth of the several sulphides and the very small amounts of each that could be separated in a guaranteed pure condition, and taking into consideration the great difficulty and length of time required for the analytical determination of the individual platinum metals, ordinary gravimetric analytical methods are also obviously quite impracticable. Microchemical methods, if applicable at all, would only have given qualitative or, in other words, partial results. In these circumstances it was decided to examine isolated fragments of the several minerals composing the ores by means of a quartz spectrograph, involving the use of ultra-violet light and specially designed for the purpose. The method which is described below proved eminently successful.

V. Examination for Platinum Metals by Means of a Quartz Spectrograph, using Ultra-violet Light, of the Individual Isolated Mineral Constituents of the Ores.

(1) Isolation of the Individual Mineral Grains.

For isolating clean grains of the different minerals and in particular those of the intimately intergrown sulphides, there was employed a method that has been in successful use for about a year in the Mineralogical Institute, Freiburg University. It was developed mainly by my assistant, H. Moritz.

An ordinary fine sewing needle is fitted into a centrally bored recess in the shaft of the smallest size obtainable of a Ventilator direct current motor. This latter is of about the size of a man's fist and develops 1/120 horse-power. It can

be driven from an ordinary lighting circuit through a lamp resistance. The needle can either be used as it is or one can cut a spiral groove around its sharp end by means of a glazier's diamond. The mineral to be isolated is put under the microscope in well-polished sections, using a magnification of about 100. The motor is taken in the hand and the point of the needle is brought into the field of vision of the microscope and on to the mineral, out of which minute fragments are then slowly and carefully bored.

The method has recently been improved upon in that the motor is fixed, and a long flexible spindle like that used by dentists is attached to its shaft, the needle being let into the end of the spindle. The borer in these circumstances can be held more steadily than when attached to the motor. Incidentally it may be remarked that in place of a needle one can employ the finest bits used by dentists.

The drilling must be carefully watched under the microscope, and stopped immediately one passes across the contact of the grain being drilled into another. As a rule this can be judged by the colour of the shavings. Differences in cohesion and resistance to boring also afford valuable criteria. The shavings that collect on the surface of the polished section are picked up by means of a pointed piece of wood, such as a sharpened match, the tip of which has been moistened. They are immediately transferred to a watch-glass filled with water which is then heated to dryness. It is possible to isolate by means of this rather laborious method, calling above all for steadiness of hand, perfectly clean fragments of a mineral even from the most intimate intergrowths. Sufficient material for a quantitative chemical analysis could be collected, but it would probably take many days to do so. For the purpose of the spectrographic examination a few milligrams suffice, and these are quickly obtained.

(2) *Approximate Quantitative Analysis by Means of the Quartz Spectrograph.*

Quantitative spectrography with the aid of the ultra-violet spectrum, using wave-lengths falling between 400 and 220 $\mu\mu$ has been developed only within the last one and a half decades. Suitable quartz spectrographs and tables of constants to be used with them have only appeared within recent years. In

regard to the principles and application of the method, the reader is referred particularly to the publications of F. Löwe (76, 77, 78), of the optical works of C. Zeiss, Jena, who designed the apparatus and has furnished directions for its use.

The Mineralogical Institute of Frieburg University has now for a year possessed a big quartz spectrograph from the Zeiss works. This has already performed wonderful service in many difficult cases of mineral analyses, particularly where only very small amounts were available.

The minute particles obtained from the platinum ores of the Transvaal in the manner already indicated, were also examined by means of this apparatus. The tiny shavings are transferred, together with a little Plastolin, into the crater of an arc-lamp carbon which, together with a second carbon, forms a pair of electrodes. These are then connected with a spark inductor. By this means the mineral is vaporised, and the ultra-violet portion of the spectrum obtained by a combination of quartz prisms and quartz lenses is photographed. In each case a separate photograph is taken of the spectra of the plastolin and the carbon electrodes. The measurement of the spectrum lines is accomplished by means of a Zeiss measuring microscope, the limits of error of which are ± 0.001 mm.

The spectrum obtained permits one in the first place to ascertain quantitatively what elements are present in the sample tested. Then, by comparing the intensity of the lines of the same element in the different samples with one another and synthetic standard solutions of known strength, and finally by the so-called method of "ultimate lines," a quantitative analysis can, with certain limitations, be made. These limitations refer particularly to the following points:—

- (1) Quantities above 1 per cent. of the substances examined are not differentiated by the spectrum and cannot thus be determined. The quartz spectrograph is therefore only sensitive where the percentage of an element present is less than 1.
- (2) Elements present in amounts of less than 1 per cent. can be compared with one another on the basis of the intensities of the spectrum lines. A suitable element present is taken as unity and the amounts of this element in other samples or of other elements

in the same sample are then expressed in terms of this unit. The values obtained are thus only relative.

- (3) For those elements of which the so-called "ultimate lines" are known (Löwe, 78) the absolute content can be determined, at least as an order of magnitude. One can then from the "atlas of ultimate lines" determine whether the amount of the element present falls within one or other of the following limits:—

between 1.0	and 0.1	per cent.
" 0.1	" 0.01	"
" 0.01	" 0.001	"
" 0.001	" 0.0001	"
less than 0.0001 per cent.		

As the "ultimate lines" of gold, silver, platinum, palladium and iridium are known, this last method was employed. The amounts of the other metals of the platinum group, of which the "ultimate lines" are not known, were then determined relatively by the second method and the results obtained estimated on the same basis as those mentioned above.

To convert the orders of magnitude, already given, to units commonly used by mining engineers, the figures obtained were expressed as grams per metric ton.¹ Thus,

1.0	per cent.	.	.	10,000	grams per ton
0.1	"	.	.	1,000	" "
0.01	"	.	.	100	" "
0.001	"	.	.	10	" "
0.0001	"	.	.	1	" "
0.00001	"	.	.	0.1	" "

- (3) *Spectrographic Examination of the Individual Constituents of the Platinum Ores of the Merensky Horizon on Schildpadnest, No. 233.*

The amounts of precious metals and certain other elements in the minerals of the felspathic pyroxenites and associated rocks of the Merensky Horizon on Schildpadnest were found, by quartz spectrographic measurements, to be as shown in the table on page 235.

¹ One gram per metric ton is equivalent to 0.1568 dwt. per long ton and to 0.1458 dwt. per short ton.—P. A. W.

	Chromite.	Olivine.	Diallage.	Nickeliferous Pyrite.	Pyrrhotite.	Pentlandite.	Chalcopyrite.	Millerite-Serpentine.
Vanadium	—	—	—	+	—	—	—	—
Iron .	+++	+++	+++	+++	+++	+++	+++	+++
Cobalt .	tr	tr	tr	+	+	+	tr	+
Nickel .	tr	tr	tr	+++	+++	+++	tr	+++
Copper .	—	—	—	—	+	+	+++	tr
Ruthenium	—	—	—	I ~ 0.1	I ~ 0.1	I ~ 0.1	—	—
Rhodium .	—	—	—	I ~ 0.1	I ~ 0.1	I ~ 0.1	—	—
Palladium .	—	—	—	100 ~ 10	100 ~ 10	10 ~ 1	—	—
Osmium .	—	—	—	tr	tr	tr	—	tr
Iridium .	—	—	—	I ~ 0.1	I ~ 0.1	I ~ 0.1	—	—
Platinum .	—	—	—	100 ~ 10	100 ~ 10	10 ~ 1	—	tr
Gold .	—	—	—	—	10 ~ 1	—	—	—
Silver .	—	—	—	—	—	—	—	—

(The figures given signify grams per metric ton.)

+++ signifies in large amounts (> 10 per cent.).

+ " in measurable quantities (ca. $\pm$ 0.1 per cent.).

tr " trace (0.0001 per cent.).

— " not detectable.

The results may be summarised as follows:—

- Chromite* is free from platinum and other platinum and precious metals.
- All the *silicates* entering into the composition of the pyroxenites and Merensky "Reef" are free from platinum and other precious metals.
- Of the sulphides, *chalcopyrite* and *millerite* contain neither platinum nor other precious metals.
- The other sulphides, *nickeliferous pyrite*, *pyrrhotite*, *pentlandite*, contain appreciable amounts of all the platinum metals. They, moreover, all contain cobalt. Nickeliferous pyrite alone contains *vanadium* and pyrrhotite alone contains *gold*; the other sulphides are free from these elements.
- The amount of the platinum metals present decreases with decreasing age of the sulphides, and in the last formed of these, namely, *chalcopyrite*, equals nil. Even in *pentlandite* it is much less than in *pyrrhotite* and *nickeliferous pyrite*, which contain roughly the same amounts. The amount of platinum and palladium present in the *pentlandite* is only about one-tenth of that in *nickeliferous pyrite* and *pyrrhotite*. The other platinum group metals—*iridium*, *osmium*, *rhodium* and *ruthenium*—are present in about the same proportions in all three sulphides.

- (f) In the three sulphides, nickeliferous pyrite, pyrrhotite and pentlandite, platinum and palladium are present in approximately equal proportions.
- (g) The amounts of iridium, rhodium and ruthenium present in the three sulphides are of about the same order of magnitude, and equal to from 1/10 to 1/100 of the platinum and palladium. The amount of osmium present in all three sulphides is of a much smaller order of magnitude.
- (h) The spectrographic analysis, as previously indicated, proves that the earliest of the sulphides is not pure pyrite but pyrite rich in nickel and containing some cobalt.

(4) *Spectrographic Examination of the Sulphides of the Contact Deposit on Zwartfontein, No. 121.*

In this deposit platinum and palladium are, as already indicated, both present as definite minerals. It was, therefore, of special interest to test spectrographically whether platinum metals are here also present in the sulphides in a sub-microscopic form.

The occurrence of the unidentified opaque ore mineral as big inclusions in pentlandite and of cubanite independently of chalcopyrite rendered it possible, moreover, to test these minerals for platinum metals.

The measurements of the spectrograms gave the following results:—

	Pentlandite.	Unidentified Mineral.	Cubanite.
Vanadium	—	tr	tr
Iron	+++	+++	+++
Cobalt	+	+	—
Nickel	+++	+++	—
Copper	+	—	+++
Ruthenium	—	—	—
Rhodium	—	—	—
Palladium	+	+	—
Osmium	—	—	—
Iridium	tr	tr	—
Platinum	—	—	—
Antimony	tr	tr	—
Silver	tr	tr	—
Gold	tr	tr	—

+++ signifies in large amounts (over 10 per cent.).

+ „ in measurable quantities (ca. ± 0.1 per cent.).

tr „ trace (0.0001 per cent.).

— „ not detectable.

The results may be summarised as under :—

- (a) The unidentified mineral, which has probably been derived by unmixing in the solid from pentlandite, is also a nickel-iron compound.
- (b) The identification of the primary, independently occurring cubanite as such is confirmed by spectrographic analysis.
- (c) The predominant sulphides in the contact deposit of Tweefontein are, in contrast with the sulphides in the ores of the Merensky Horizon, notably poor in platinum metals. Platinum itself is entirely absent. Iridium is present in the pentlandite in traces only. Palladium is present in somewhat larger amounts in the pentlandite and its unmixing product, but still in much smaller amounts than in the sulphides of the Merensky Horizon. The other metals of the platinum group and gold and silver are present in the pentlandite in traces only.
- (d) The last-formed sulphide, cubanite, is here too entirely free from platinum metals.

(5) *Spectrographic Examination of Sperrylite, Cooperite and Stibiopalladinite.*

The spectrographic examination of these minerals gave the following results :—

	Sperrylite of Tweefontein, Potgietersrust.	Stibiopalladinite of Tweefontein, Potgietersrust.	Cooperite of Klipfontein- Kroondal Mine, Rustenburg.
Cobalt	—	—	—
Nickel	—	—	—
Ruthenium	—	—	—
Rhodium	tr	tr	tr
Palladium	+	+++	+
Osmium	—	—	—
Iridium	+	tr	tr
Platinum	+++	tr	+++
Antimony	—	+++	—
Silver	tr	tr	tr
Gold	tr	tr	tr

(The symbols have the same significance as in the previous tables.)

The spectrographic analysis confirms in a general way the results of the mineragraphic and chemical examination of the

three minerals. The complete absence of nickel and cobalt is worthy of special note.

VI. Summary of Results and Conclusions as to the Genesis of the Ores.

From the account of the geological relations and the mineralogical and microscopic descriptions of the ores of the Bushveld Igneous Complex published by Dr Wagner and Dr E. Reuning, and the foregoing mineragraphic and spectrographic observations, the history of the formation of the platinum-bearing rocks described is found to be as follows.

First Phase.—The first phase embraces the *earliest crystallisations* from the magma. Arranged in the order of their formation, the following minerals separated during this phase from the intrusive igneous rocks of the norite lopolith.

± Chromite	Bronzite
± Titaniferous Magnetite	Labradorite-Bytownite
Olivine	Diallage.

According to the relative proportions of these minerals separating there were formed diallage-norite, bronzitite or pyroxenite, feldspathic harzburgite, chromitite or magnetite. Rocks and mineral deposits of this nature may, following P. Niggli (82) and H. Schneiderhöhn (87) be designated

liquid-magmatic.

They owe their origin to the direct crystallisation of the difficultly fugitive constituents of the magma. In the Bushveld Complex the chromitite seams and bands and the stratiform segregations and schlieren of titaniferous magnetite belong to the category of the *liquid magmatic* deposits.

As the ore minerals separated here as the earliest constituents of a normal crystallisation-differentiation series, H. Schneiderhöhn (87) has designated such deposits

crystallisation differentiates.

The minerals of this earliest period of crystallisation contain in the rocks examined by me no trace of any platinum metals, as was also proved spectrographically.¹

¹ The specimens examined by Professor Schneiderhöhn unfortunately did not include the platinum-bearing chromitite of the upper horizon in which, as we have seen, platinum is widely distributed.

Second Phase.—Immediately succeeding this earliest period is the *second phase*, of which there is evidence in many igneous rocks, but which is exceptionally well represented in the rocks under description and intimately related to their content of platinum-bearing sulphides.

Even before the chromite began to separate or, in other words, before any actual crystallisation began, another event had taken place in the magma, namely, the separation of the liquid sulphide melt from the silicate-oxide melt. From the investigations of J. H. L. Vogt (58, 91) we know that the two melts can already become immiscible at very high temperatures, and that their separation in a liquid condition takes place round about 1500°C. It is practically complete when the earliest oxides and silicates begin to crystallise. At this stage there are thus present two immiscible fluids of which the one, the oxide-silicate melt, crystallises completely before the other, namely, the sulphide melt, begins to consolidate. In consequence the sulphide melt collects in the interstices between the crystallising silicates in the form of drops. It crystallises itself only long subsequently at a much lower temperature. The sulphides then formed give rise to a second type of *liquid magmatic* deposit. I designated this a

liquid exsolution segregate

borrowing a term from the sister science of metallography (87). It implies that the concentration of such magmatic sulphides was the result of exsolution or unmixing in the liquid state, giving rise to a segregate.

It is well known that all magmas contain not only *difficultly fugitive* components from which, in the first place, oxides and silicates are formed, but also large quantities of *readily fugitive*¹ compounds. These are present in solution and include above all water, but also H₂S, CO₂, SO₂, Cl, F, B, etc. Such fugitive or volatile constituents become more and more concentrated in the rest-magma, and we must assume that the unmixed sulphide melt also becomes increasingly rich in them. In these circumstances, however, the silicates that crystallised out during the earliest phase become in part unstable and react with this rest-magma. As a consequence there are formed *reaction* or *syntectic minerals* (89), or, putting it in another way, the ores suffer

¹ Leichtflüchtige.

autometamorphism even during consolidation (23). The reaction minerals in the ores under discussion are hornblende and biotite, which originate as parallel growths from diallage, bronzite and labradorite. Microscopic evidence proves beyond all doubt that these minerals crystallised at about the same time as the sulphides and that their periods of formation overlapped.

An especially characteristic mineral of this phase is graphite. The formation of this mineral, to which P. A. Wagner makes frequent reference, falls between that of the sulphides and that of the reaction silicates. It is, without doubt, already a product of the readily fugitive constituents and formed by gaseous reaction. Different reactions of this nature are theoretically possible, *e.g.* reduction of CO or CN through the action of carbides or carbonyls.

The second phase is thus characterised by the paragenesis: *hornblende, biotite, graphite and sulphides.*

Within the sulphide aggregates too a definite succession can be made out. This embraces first the primary minerals that separated direct from the sulphide melt. The latter then consolidated and later, as a result of unmixing in the solid, there separated from it a second generation of minerals. The succession is the same in all the specimens examined. Taking into account all the sulphide minerals observed, the paragenesis is as follows, unmixing or exsolution being indicated by an arrow.

Nickeliferous pyrite.

Pyrrhotite $\rightarrow$ secondary pentlandite.

Primary graphite.

Primary pentlandite $\left\{ \begin{array}{l} \rightarrow \text{secondary cubanite.} \\ \rightarrow \text{unidentified ore mineral.} \\ \rightarrow \text{secondary graphite.} \end{array} \right.$

Chalcopyrite $\rightarrow$ secondary cubanite.

In the different rocks examined and in the different districts in which the Merensky "Reef" is developed, different combinations of these sulphides are present. Nickeliferous pyrite was only found in the Schildpadnest ore, and in this the pentlandite is free from the unidentified nickel-iron mineral that is of common occurrence elsewhere. Further, the relative proportions of the several sulphides differ widely. In so far as we have not to do here with primary differences in the concentration Fe:Ni:Cu, the differences are probably due in

the main to differences in the vapour pressure of sulphur. Thus, for instance, the presence of a bisulphide at Schildpadnest points to there having been a much higher sulphur vapour tension here than elsewhere, if we may assume, as appears probable, that the crystallisation periods in all these petrographically similar rocks were much the same.

Of great importance from our point of view is the fact that it was in this second phase of the liquid-magmatic stage that the platinum metals for the most part crystallised. During the earliest phase of crystallisation they had clearly entered completely into the sulphide melt with its high content of readily volatile constituents.

V. M. Goldschmidt has shown in his classic investigations on the laws of distribution of the elements that, from the geochemical point of view, the platinum metals are predominantly "siderophile" elements, but that they also show "chalcophile" affinities dependent on external conditions, temperature, pressure, concentration and association.

In the present state of our knowledge one may perhaps be permitted to state that the platinum metals, in the absence of sulphur, arsenic and antimony, are strongly siderophile and crystallise out in the native or metallic state. Where, however, sulphur, arsenic or antimony are present in a certain concentration, they just as readily enter into combination with these elements and then show a chalcophile tendency.

Of great interest is the further behaviour of the platinum metals in the several phases of the magmatic cycle, or, in other words, in the different fields of temperature and pressure marking the course of the cycle.

It should be pointed out first that the platinum metals, speaking generally, show a marked disposition to separate out at the beginning of the magmatic cycle within the liquid magmatic stage. Why then do they enter in solid solution into the sulphides? How do we explain their being relatively abundant in the nickeliferous pyrite and pyrrhotite, and far less so in the pentlandite? And why do we find, in contrast with the conditions obtaining in the intrusive rocks, that in the pegmatites and contact deposits the platinum metals have been individualised in definite minerals? To all these problems the recent investigations of V. M. Goldschmidt (72) furnish satisfactory solutions. Atomic structure and the crystallo-

chemical relations dependent on it are here the main factors involved. From the results of our own chemical and spectrographic investigations there can be no doubt that the platinum metals are present in the sulphides in solid solution and not in mechanical admixture. According to the conceptions developed in recent years, particularly by H. Grimm and V. M. Goldschmidt (72), the atomic or ionic radii of elements play a particularly important rôle among other factors in determining their ability to form isomorphous mixtures with, or in other words, to enter isomorphously into the space lattices of the crystals of other elements. As the platinum-bearing sulphides with which we are concerned are conductors of electricity and thus are homeopolar compounds possessing space lattices, the atomic radii of the metallic elements which they contain must here be taken into consideration. These radii, according to the data given by V. M. Goldschmidt, are as follows:—

Table of Apparent Atomic Radii.

Ni	.	.	.	.	.	1.24×10^{-8} cm.
Fe	.	.	.	.	.	1.26
Co	.	.	.	.	.	1.26
Ru	.	.	.	.	.	1.30
Os	.	.	.	.	.	1.31
Rh	.	.	.	.	.	1.34
Ir	.	.	.	.	.	1.35
Pd	.	.	.	.	.	1.37
Pt	.	.	.	.	.	1.38

The biggest difference, that between nickel and platinum, is, at ordinary room temperatures, almost exactly 10 per cent. The other differences are materially smaller.

V. M. Goldschmidt has shown, using a great wealth of experimental material, that the limits of tolerance for general replaceability in the space lattices amounts to about 10 per cent. of the atomic or ionic radius. It follows from this that, provided that sufficient sulphur, arsenic and antimony are present, it is possible for all the platinum metals to enter into isomorphous solution in the iron-nickel sulphides, particularly as the mutual solubility increases at higher temperatures. That the metals named have not the same valency is of no significance, as close crystallographic relationship, notwithstanding divergent valencies, is a common and recognised phenomenon.

Sperrylite and pyrite have actually the same crystal structure. An appreciable solubility of the platinum arsenide in the nickeliferous pyrite would thus be expected from the crystallographic point of view.

We may therefore take it for certain that, at high temperatures with a sufficiently high concentration of sulphur, arsenic and antimony, the platinum metals enter into isomorphous solution in the sulphides of iron and nickel. And the microscope proves that no unmixing takes place with a fall of temperature.

The three sulphides, pyrrhotite, nickeliferous pyrite and pentlandite appear to be about equally favourably constituted for taking up the platinum metals isomorphously. That in the ores of Schildpadnest nickeliferous pyrite and pyrrhotite contain the bulk of the platinum metals, while pentlandite contains appreciably smaller amounts of them, may be due to the relative ages of these minerals, the earliest formed sulphides always taking up the most platinum. In other ores, poor in pyrrhotite and free from nickeliferous pyrite, for example those of Zwartfontein, pentlandite is the principal platinum-bearer.

Chalcopyrite and cubanite are always free from platinum metals. This is probably due partly to their fundamentally different crystal structure but mainly to their being the last-formed of the sulphides, which were still fluid when the whole of the platinum metals had already been concentrated in the earlier formed sulphides.

The platinum content of the sulphides, in particular nickeliferous pyrite and pyrrhotite, appears to me to account for the abnormally high resistance that they offer to etching or, in other words, for their insolubility in acids. The concentration of the platinum metals on certain planes of the crystal lattice protects them directly from attack by acids including even aqua regia. This is probably also the reason of the difficultly soluble nature of part of the platinum metals contained in the ores of the Merensky Horizon.

Third Phase.—The crystallisation of the several sulphides named ended the liquid-magmatic stage. Residual solutions remained over. These, however, were no longer strictly magmatic but had more the character of pneumalolytic or even hydrothermal solutions. The *pegmatites* of Tweefontein

afford a transitional stage from the liquid-magmatic to the pneumalolytic phase. E. Reuning (59) regards them as acid after-intrusions (*nachschübe*) of the Red Granite of the Bushveld, while Wagner¹ interprets them as residual rest-magmas squeezed out of the norite. In any case their pegmatitic nature points to their having consolidated at a much lower temperature than the pyroxenites and norite. And here, be it noted, we find definite platinum minerals in the shape of sperrylite and stibiopalladinite accompanying the pyrrhotite and chalcopyrite.

The other occurrence of these platinum-metals minerals is in the contact deposits of Zwartfontein, and there also under conditions pointing to a much lower temperature of formation. The obvious conclusion is that at the temperature of formation of these deposits, which was evidently some hundreds of degrees lower than that of the pyroxenites and norites, platinum and palladium were no longer capable of entering into the lattices of the iron-nickel-sulphides. This applies particularly to platinum. In the sulphides of Zwartfontein not a trace of this metal can be detected even spectrographically, while palladium is still present in very subordinate amounts. Here the limits of tolerance of the immiscibility had thus clearly been passed. Whether the higher copper and the lower nickel concentration in the pegmatites had anything to do with the separate crystallisation of the platinum metals is doubtful, since in the contact deposits much nickel is again present.

We conclude, therefore: that *under pneumalolytic and contact-pneumalolytic conditions iron-nickel sulphides on the one hand, and platinum arsenide and palladium antimonide on the other, crystallised independently.*

Fourth Phase.—In addition to the phases of the crystallisation-differentiation, liquid exsolution-segregation and pegmatite or contact silicate formation, a fourth phase is recognisable in these rocks. While the two first-named phases fall entirely in the liquid-magmatic field, and the third has its centre of gravity in the pneumalolytic field, the fourth falls in the *hydrothermal field*. It was brought about by the evolution as a result of the progressively decreasing temperature of small amounts of superheated steam and similar readily fugitive

¹ Quoted by Reuning (59).

constituents that became liberated as a consequence of the consolidation of the magma. These reacted with the silicates and also slightly with the sulphides. Along miniature brecciated and stringer zones formed by endogenetic movements (*e.g.* contraction due to cooling) the silicates are serpentinised and carbonated and traces of the sulphides dissolved concomitantly have been reprecipitated as millerite.

The *hydrothermal generation* of minerals thus comprises:—

Serpentine	Ca-Mg Carbonates	Millerite.
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The spectrographic examination of the serpentine-millerite aggregates proves that small amounts of the platinum metals were dissolved and reprecipitated by these hydrothermal processes, but in what form the platinum metals were deposited is not known. Owing to the extremely fine nature of the intergrowths, the microscope failed to yield any tangible evidence on this point. Judging, however, by analogy with the hydrothermal platinum-specularite-quartz veins of the Waterberg, described by Wagner (27), I surmise that they separated here in the native state in a highly disperse condition.

Finally, we can follow the circulation of the platinum metals even down to ordinary surface temperatures. The highly decomposed pyroxenite from the oxidised zone on Zwartfontein Central carries native platinum metals in the form of concentric concretions. The sulphides have been completely oxidised and the other heavy metals all leached away, the platinum metals alone having been reprecipitated *in situ*.

To complete the list of the platinum occurrences of the Transvaal mention should also be made of the after-intrusions (*nachschübe*) of liquid-magmatic hortonolite-dunite with their native platinum, and the hydrothermal platinum-specularite-quartz lodes of which Dr Wagner has given a full description.

Actually the rocks and mineral deposits of this province give us within a small compass, so far as the platinum metals are concerned, a clear picture of the processes involved in what, according to the very important investigations of V. M. Goldschmidt, P. Niggli and others, are the fundamentals of ore geology, namely: *the metabolism of the earth and the laws of distribution of the chemical elements within its crust.*

Acknowledgments.

It is a pleasant duty here to thank those who placed at my disposal the rocks and ore specimens forming the basis of this investigation, namely: Professor Dr E. Kaiser, Professor Dr H. Lotz, Dr E. Reuning and Dr P. A. Wagner.

For assistance in the carrying out of my work I am indebted to the *Notgemeinschaft der Deutschen Wissenschaft*, the Union Minerals Exploration Syndicate, Limited, of Johannesburg, the Potgietersrust Platinums, Limited, and Messrs H. Moritz and H. Frick, of the Mineralogical Institute, Freiburg University.

CHAPTER XVIII

THE PLATINUM DEPOSITS OF THE GREAT DYKE, SOUTHERN RHODESIA¹

THE Great Dyke is, in many respects, the outstanding geological feature of Southern Rhodesia.

It is a remarkable intrusion that extends for some 350 miles in a general north-north-east to south-south-west direction through the territory, its average width being about 4 miles. It is composed of basic and ultrabasic rocks bearing a fairly close family resemblance to those of the Norite Zone of the Bushveld Igneous Complex, and is thus almost certainly related genetically to the Bushveld Igneous Complex.²

The rocks composing the Great Dyke are, like those of the Bushveld Igneous Complex, as a rule very distinctly pseudo-stratified, and exhibit a symmetrical synclinal arrangement dipping inward from both sides of the great intrusion (Fig. 34). This fact led the writer to conclude³ that the Great Dyke is not strictly a dyke but of the nature of a very elongated laccolith or, more correctly, lopolith. Were some 15,000 feet of rock removed from the Central Transvaal there might possibly be left here a feature very similar to the Great Dyke, striking from east-north-east to west-south-west.

The principal rock types entering into the constitution of the Great Dyke are as follows:—

- (1) Pyroxenites: bronzitite, or enstatite, as the officers of the Geological Survey of Southern Rhodesia prefer to term it, and olivine-bronzitite.
- (2) Harzburgite.
- (3) Serpentine derived from olivine-dunite.
- (4) Chromitite.
- (5) Felspar-rich or anorthositic norite.

¹ Lightfoot (62 and 63).

² Zealley (20), Wagner (26 and 36).

³ Wagner, P. A., *Trans. Geol. Soc. of S. Africa*, 1914, p. 51.

Serpentine, with chromitite seams or harzburgite generally form the outermost or peripheral part of the dyke. Then follows pyroxenite, the felspar-rich norite, where present, forming the innermost or central part of the great intrusion, and giving rise to persistent ridges or plateaux. A generalised section across the dyke based on one prepared by Lightfoot (63) is given in Fig. 34.

The Platinum Deposits.—The earliest discovery of platinum in the Great Dyke was made in 1918, when small

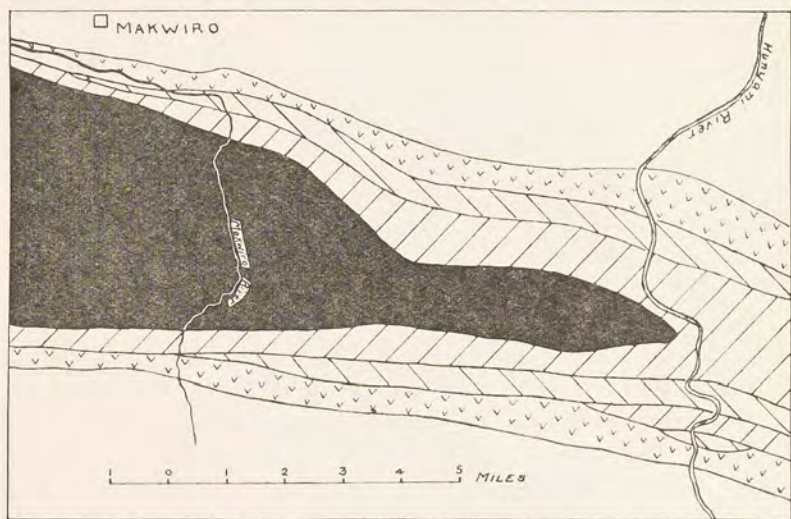


FIG. 33.—Plan of Portion of the Great Dyke of Southern Rhodesia, near Makwiro. *After* B. Lightfoot (62).

amounts of the metal were found¹ 6 miles north-east of Indwa Siding, in the Gwelo district, in a body of serpentinised dunite.

A sample of concentrate from an unstated amount of dunite was forwarded to the Imperial Institute, London, and was found on assay to contain platinum to the amount of 1 dwt. 20 gr. per ton. The occurrence proved to be too poor to be worthy of exploitation.

It was only after the discovery of the Bushveld deposits that systematic prospecting work for platinum was undertaken

¹ Zealley (19).

along the Great Dyke. This led quickly to the discovery of platinum at three widely separated localities, to which reference will presently be made. Geological investigations made by B. Lightfoot proved that the conditions under which the metal occurs are much the same at all three localities, and enabled him to make the important generalisation that platinum is only found in notable quantities in those areas of the dyke where the felspar-rich norite is present. It occurs then as a sheet or layer lying from 20 to 60 feet below the base of the felspar-rich norite, which clearly stands in a complementary relation to the platinum reefs and the associated pyroxenites.

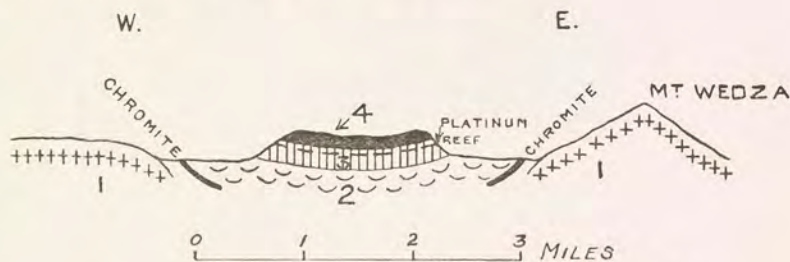


FIG. 34.—Diagrammatic Section across Great Dyke at Wedza Platinum Mine.

- | | |
|------------------------------------|-------------------------|
| 1. Old Granite. | 3. Bronzite. |
| 2. Serpentine, with Chromite Seam. | 4. Anorthositic Norite. |

The felspar-rich norite, which at one time was evidently far more widely distributed than it now is, is present in three big sectors of the dyke, namely, (1) that lying between the Hunyani and Ngesi rivers and embracing the Makwiro platinum field; (2) that embracing the Selundi Hills east of Selukwe, where platinum has also been found; (3) that extending from near the Umgezi River to the Umchinwe River in the Belingwe district, and including the Wedza platinum field. The last-named appears to be the most important of the sectors. A great deal of work has been done here on the Wedza claims belonging to Messrs Granger Brothers. A generalised section across the dyke in this area is given in Fig. 34.

Platinum is found in a fairly well-defined "reef" from 8 to 10 feet thick, only the uppermost 3 or 4 feet of which, however, carry notable amounts of the metal. A detailed

section across the "reef" made by the writer shows, in descending order:—

Hanging-wall felspathic pyroxenite . . .	thickness unknown
"Potato Reef" (platinum-bearing) . . .	16 feet to 2 feet 9 inches
"Reef" (platinum-bearing) . . .	3 to 4 feet
Rather fine-grained "Merensky Reef," barren	6 feet

The "Potato Reef" consists of flattened oval-shaped nodular bodies of rather fine-grained pyroxenitic norite with lath-shaped phenocrysts of bronzite in the matrix of medium-grained bronzitite of the same nature as that forming the underlying "reef." In places the uppermost 6 inches of the "Potato Reef" show secondary nickel stains, and this sector is in consequence referred to as the "Nickel Band." There is generally a well-defined parting between the "Potato Reef" and the overlying barren felspathic pyroxenite. This is visible in the accompanying photograph (Plate XXXIII.1).

The "reef" underlying the "Potato Reef" is a medium-grained pyroxenite composed predominantly of lath-shaped criss-crossing crystals of bronzite or, more correctly, clinobronzite, the crystals being twinned polysynthetically parallel to (010) as in the platinum deposits of the Bushveld Complex. The "Reef" and "Potato Reef" are stained with secondary limonite, malachite and, more rarely, with secondary nickel minerals evidently derived from the oxidation of the usual magmatic iron-nickel-copper sulphides. The analysis of a typical specimen of the "reef" is given in column I. of the table¹ on page 251, and one of the footwall Merensky "Reef" in column II.

Both the "Potato Reef" and the "reef" are said to carry an average of 3 dwts. of platinum, the platinum values being here apparently associated with the secondary ore minerals already referred to. An examination of a concentrate kindly placed at my disposal by Mr E. Golding, of the Geological Survey of Southern Rhodesia, proved that the platinum is present mainly as minute cubo-octahedrons of sperrylite. Minute flattened crystals probably represent cooperite. The presence of that mineral is also indicated by the fact that

¹ These analyses were specially made for the writer and he desires here to express his indebtedness for them to Mr H. B. Maufe, Director of the Geological Survey, Southern Rhodesia, and to Mr E. Golding.

PLATE XXXIII



1. Exposure of platinum "reef" in one of the adits, Wedza Platinum Mine, Great Dyke, Southern Rhodesia. The parting between the hanging-wall pyroxenite and the platinum-bearing "Potato Reef" is indicated by the prospecting pick.



2. Treatment Plant on the Wedza Platinum Mine, Great Dyke, Southern Rhodesia.



Mr R. A. Cooper found that the concentrate contains 2 per cent. of sulphur which cannot be assigned to any other mineral present. According to the same authority, the concentrate itself contains notable amounts of sulphur.

Makwiro Area.—In the Makwiro area, where a considerable amount of work was done in 1925 and 1926, the platinum-bearer is rather fine-grained "Merensky Reef," that is, pseudo-porphyrific poikilitic diallage-norite with pseudo-phenocrysts of diallage up to 1 cm. across. It forms a sheet lying about 30 feet below the base of a layer of felspar-rich norite.

	I.	II.	III.
SiO ₂	53.50	53.14	52.65
TiO ₂	0.22	0.16	0.14
Al ₂ O ₃	5.81	5.36	3.90
Fe ₂ O ₃	2.40	2.85	2.18
FeO	8.32	6.93	10.29
MgO	22.53	22.48	25.94
CaO	4.93	4.67	3.46
Na ₂ O	0.21	0.18	0.40
K ₂ O	0.08	0.07	0.03
H ₂ O	0.31	2.44	0.27
H ₂ O	1.08	1.20	0.23
CO ₂	nil	...	0.22
P ₂ O ₅	0.12	0.18	0.11
S	nil	0.03	...
Cr ₂ O ₃	nil	...	...
MnO	0.29	0.19	0.18
NiO	nil	...	0.25
SrO	trace	0.08	...
Totals	99.80	99.96	100.25
Specific gravity . . .	3.06	3.067	3.23
Analyst, E. Golding.			
Symbol	IV. 1.1.2.2	IV (1).1.1.2.2	IV. 1.1.1.2

The "Merensky Reef" is rather fine-grained and carries less diallage than the normal "Merensky Reef" of the Bushveld occurrences, but closely resembles the "Bastard Reef" as developed in parts of the Rustenburg and Lydenburg districts. According to Lightfoot (63) the platinum-bearer is seen in thin sections to consist of pseudo-phenocrysts of diallage lying in a matrix composed of enstatite and augite in almost equal proportions, together with interstitial felspar which seems to be in optical continuity over large areas. According to this description

it differs from the Transvaal rock in containing augite. An analysis of the platinum-bearer is given in column III. of the table on page 251.

The ore, which shows the usual copper and iron stains, carries up to 3 dwts. of platinum per ton, but the metal appears here to be patchy in its distribution.

It will be noted that all three of these Rhodesian rocks are very similar in composition to, and that No. III. falls in the same subrang as, the Merensky "Reef" of the type occurrences in the Transvaal, of which analyses are given in Chapter X.

CHAPTER XIX

OTHER OCCURRENCES OF THE PLATINUM METALS IN SOUTH AFRICA

SOME years ago Colonel J. G. Rose, a careful and accomplished chemist, while in charge of the assay department of the Government Chemical Laboratory, Cape Town, examined a large number of rocks from different parts of the Cape Province for platinum. As a result of his investigations he came to the conclusion that platinum is fairly generally distributed in minute traces through the igneous rocks of that province. Among the rocks tested were different types of granite, dolerites from the Karroo and Graaff Reinet, and gabbro-norites from the Transkei. In no case did the quantity amount to more than a grain or two per ton. Recently he has again taken up these investigations and has been able to confirm the conclusions previously reached.¹ As a matter of general interest it may be recorded that special tests were made with blank charges to test the purity of the reagents used. Colonel Rose found that the "pure" borax of commerce, which is fused in platinum crucibles, is not infrequently contaminated with platinum.

Occurrences in the Diamond-Bearing Conglomerates and Gravels of Somabula Fields.

The diamond-bearing conglomerates and gravels of the Somabula Fields near Gwelo, Southern Rhodesia, have been proved to contain small amounts of the platinum metals. A sample of the heaviest fine concentrate obtained in the washing for diamonds was tested at the Imperial Institute, London, and found to contain: "Platinum, 3 oz. 12 dwts. per ton of concentrate." Palladium was probably present, but the amount was too small to be definitely identified.²

¹ Personal communication to the writer.

² Cf. Short Report No. 5, *Southern Rhodesia Geol. Surv.*

The Somabula conglomerates are of Upper Karroo age (Triassic). They contain rolled pebbles of fine-grained chromite which, as the writer originally suggested,¹ probably have their source in the Great Dyke. It is very likely, therefore, that the platinum metals present were also derived from that remarkable intrusion. This view receives support from the fact that Zealley noted in the conglomerate and gravels pebbles of silicified serpentine derived from the Great Dyke.²

Occurrences in Karroo Dolerite and in Rocks Allied to Karroo Dolerite.

The most important deposits under this head are the magmatic nickel-copper occurrences of Insizwa and Tabankulu in Griqualand (East), Cape Province, which are well known among geologists through the writings of Rose,³ du Toit⁴ and Goodchild.⁵

The deposits occur near the lower contacts of great basin-shaped masses of gabbro-norite—a special phase of the well-known Karroo dolerite—which have been shown to be remnants of a vast sill intrusive in the lower division of the Beaufort Series of the Karroo System. The lower surface of the sill was evidently of an undulating nature. The existing occurrences represent the parts filling the hollows, the intervening dome-like connections having been removed by denudation. The individual gabbro masses show gravity stratification. They range in composition from gabbro with interstitial micropegmatite, at the top, through olivine-gabbro and olivine-norite to picrite at the bottom. The lowest layer of all is gabbro, evidently a chilled contact phase of the parent magma. The nickel-copper sulphides are associated with the picrite. In the Insizwa deposit both disseminated sulphide ore and massive sulphide ore are present; the former occurring as a

¹ *The Diamond Fields of Southern Africa.*

² Short Report No. 5, *Southern Rhodesia Geol. Surv.*

³ Cf. Rose, J. G., *S. A. Journ. Sci.*, vol. vii., pp. 129-131, Cape Town, 1911.

⁴ Du Toit, A. L., *Geol. Surv. Un. of South Africa, Annual Report* for 1912 and 1913; *Ann. Rept. Geol. Comm. Cape of Good Hope* for 1910-1911; "The Geology of the Transkei. An Explanation of Sheet 27 (Cape)," *Geol. Surv. Un. of South Africa*, pp. 18-27.

⁵ Goodchild, W. H., "The Economic Geology of the Insizwa Range," *Trans. I.M.M.*, Bulletin 147, London, 1916.

big sheet-like body of rather low-grade ore; the latter in veins and stringers and fairly extensive bodies of tabular shape.

Du Toit estimates that the disseminated sulphide ore making up the bulk of the deposit averages from 2.5 to 3.5 per cent. of nickel plus copper, these metals being present in approximately equal proportions. The ore-minerals are pyrrhotite, chalmersite,¹ pentlandite, and chalcopyrite with smaller amounts of bornite, niccolite, and zinc blende. That small amounts of the platinum metals are present was first established by J. G. Rose. Assays of several ounces to the ton have been recorded, but the average appears to be between $\frac{1}{2}$ dwt. and 1 dwt. per ton. It was always assumed that



FIG. 35.—Section across Gabbro-Norite Picrite Intrusion, Insizwa, Cape Province.

(After A. L. du Toit, *Trans. Geol. Soc. S. Africa*, 1920, p. 19.)

platinum predominated and that it was accompanied by subordinate amounts of palladium. Recent tests by a world-renowned ore-extraction firm on a bulk sample of the ore proved, however, that in this particular sample palladium only was present.

There is a consensus of opinion among geologists who have visited the occurrence that the mineralised zone on which most of the exploratory work has been done at Insizwa is the eastern edge of a large concealed lens-shaped mass of ore. To test this hypothesis, an inclined tunnel was driven into the mountain side some years ago, along the lower contact of the ore-body which dips inwards at about 22 degrees. Unfortunately the available funds were exhausted before any definite conclusion could be reached. At present the deposit

¹ Cf. Pinger, A. W., quoted by Wandke, A., and Hoffmann, R., *Econ. Geol.*, 1924, p. 202.

is not being developed, but it was announced recently that further capital had been raised for carrying out this exploratory work.

In the neighbouring gabbro-norite mass of Tabankulu smaller bodies of the same type of ore have been located.

Apropos of the foregoing it is of interest to recall that Colonel J. G. Rose, in his investigations, previously referred to, on the platinum content of the igneous rocks of the Cape Province, found that minute traces of platinum metals are fairly generally distributed through the dolerites of the Karroo.

Appreciable amounts of platinum are said to have been found many years ago in a hybrid acidified Karroo dolerite at Bekkers Kloof, near Cradock, Cape Province. So far as the writer is aware the statement has never been confirmed.

During 1921 great interest was aroused by the news of important platinum discoveries in the neighbourhood of the village of Cala situated 80 miles north of Queenstown in the Transkei division of the Cape Province. The metal was alleged to occur in a great dyke of decomposed Karroo dolerite intrusive in the Stormberg beds, and in eluvial and alluvial deposits derived from this source.

Fairly high assays were recorded both from the dolerite and from the detrital deposits. Subsequent investigations by independent engineers failed, however, to substantiate the claims made in respect of these deposits, and nothing has been heard of them since. There are thus strong reasons for doubting the authenticity of the original finds. The same applies to the alleged discoveries of platinum made some twenty years ago near Grahamstown in ochreous shale belonging to the Witteberg Series.

Occurrence in Kimberlite.

The late Victor Hartog¹ succeeded some years before his death in establishing the presence of small amounts of the platinum metals in the kimberlite of all the more important South African diamond pipes, namely, Kimberley, De Beers, Bultfontein, Du Toit's Pan, Wesselton, Jagersfontein, and Premier.

The platinum metals were found in every instance to be

¹ Cf. Wagner, P. A., *The Diamond Fields of Southern Africa*, p. 77.

associated with the chromite of the kimberlite. In addition to platinum, iridium or osmium, or, as is more probable, both these metals, are present.

The kimberlite pipes, it should be stated, are of either late Cretaceous or early Tertiary age.

The Platinum Deposits of the Waterberg District.¹

These deposits, which have attracted world-wide notice, are situated in hilly country in the Central Transvaal some eight miles west-north-west of Naboomspruit station on the Pretoria-Pietersburg railway. They take the form of brecciated quartz lodes occupying faults of post-Karoo age in felsite and felsite-tuff belonging to the Bushveld Igneous Complex. A number of lodes have been discovered in a strip of country some 18 miles in length. They have a prevalent E.N.E. to W.S.W. or N.E. to S.W. trend. Small local concentrations of platinum have been found in most of the lodes, but workable bodies of ore have so far been opened up only in the so-called Main and Branch lodes on Rietfontein, No. 3, and Welgevonden, No. 1772.² These were exploited during the years 1924-1926 by the *Transvaal Platinum Limited*.

The Main Lode can be traced at the surface without a break for $2\frac{1}{2}$ miles. It ranges in thickness from 6 feet to 60 feet, and dips to the south-east at from 60 degrees to 75 degrees. Near the boundary fence of the farms Rietfontein, No. 3, and Welgevonden, No. 1772, it sends off a branch into its hanging-wall. This can be followed for a distance of 1240 feet. It varies in thickness from 4 feet to 30 feet. It was from this Branch lode that some of the richest ore found has been obtained.

The Main and Branch lodes present much the same features and are what are known as composite lodes. Their filling varies greatly in character. In places it consists of a number of more or less closely spaced quartz stringers separated by strips or tabular masses of felsite, sometimes of considerable thickness. The quartz stringers everywhere exhibit comb structure, being made up of slender crystals

¹ Cf. Wagner, P. A., and Trevor, T. G. (27).

² Small amounts of platinum have also been found in similar lodes on the farm Elandsfontein, No. 1782, situated 38 miles south-west of these occurrences.

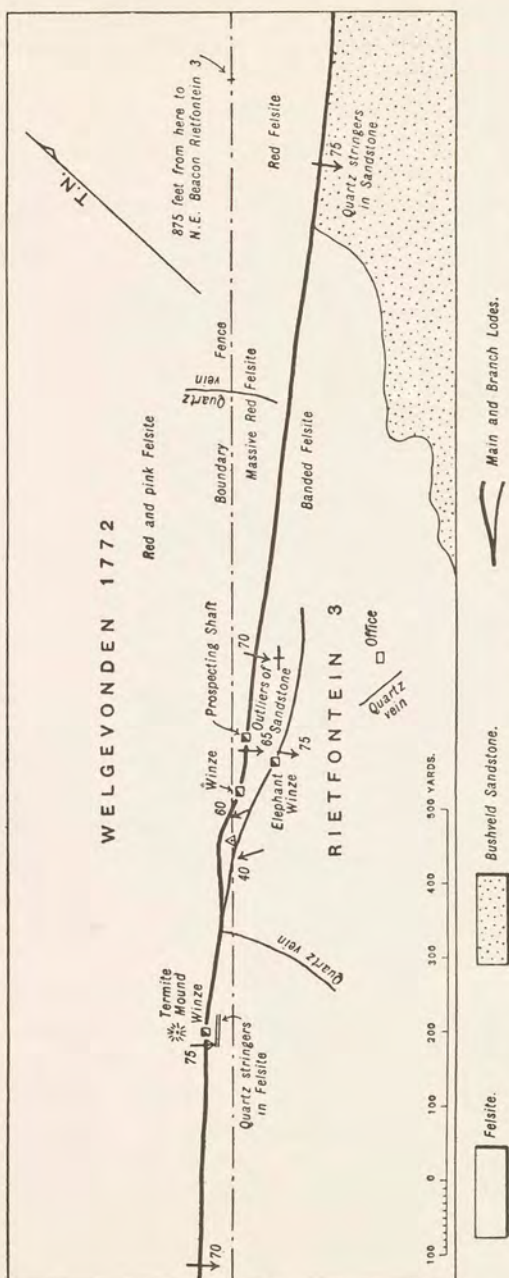


FIG. 36.—Plan of Platinum Lodes opened up on Rietfontein, No. 3, and Welgevonden, No. 1772, Waterberg District, Transvaal.

of opaque white quartz arranged at right-angles to the walls. The combs are invariably banded or crustified as a result of breaks in the inward growth of the quartz crystals which appear, as a rule, to have coincided with the deposition of thin layers of other minerals.

More commonly the lode matter is conspicuously brecciated, angular fragments of pink and red felsite and or earlier-formed quartz combs, generally accompanied by specularite, lying in a matrix of later white quartz interspersed with vughs lined with quartz crystals. A true cockade structure is in places developed. Even a casual examination of the lode matter makes it apparent that there must have been several periods of brecciation and quartz deposition. At least four such periods can be distinguished, and at an even later stage, after still further brecciation, greenish, yellow, and brown chalcedony was deposited in irregular veins and crusts.

The mineralogy of the deposits is comparatively simple. Apart from the quartz and chalcedony there are present specularite, secondary iron oxide (mainly hematite) evidently derived from the oxidation of pyrite, pale-green sericite, deep leek-green chromiferous chlorite, kaolin, and pyrolusite. The last was noted only in one specimen where it forms botryoidal crusts composed of slender fibres lining a vugh. Chromiferous chlorite is fairly abundant, but no mineral containing either nickel or copper is present.

Platinum is rarely visible except in specimens of the very rich ore in which small grey or greyish-yellow metallic specks can be made out with the aid of a lens. On polished surfaces of such ore the platinum shows up much better in bright silvery-white specks. The platinum is present in two distinct generations. That of the earlier generation occurs in irregular forms with ragged edges, also in colloform globular and reniform grains. The grains range in diameter from 0.04 to 0.6 mm. In some of the concentrically banded quartz combs the metal occurs in peculiar club-shaped and pear-shaped forms as a consequence of having been deposited between radially disposed quartz crystals. The platinum of this generation is, as a rule, intimately intergrown with specularite, or imbedded in aggregates composed of crystals of that mineral. The platinum of the second generation forms minute microscopic grains imbedded in secondary iron oxide evidently derived from the

oxidation of pyrite which was in some instances clearly moulded on the platinum of the earlier generation.

The platinum, as appears generally to be the case with lode platinum, is alloyed with palladium, containing from 7 to 45 per cent. of that metal. Iridium and other metals of the platinum group are present in traces only, but analyses prove that the platinum contains from 0.3 to 3 per cent. of gold. An interesting fact brought out by analytical work is that there is a marked difference between the composition of the platinum of the Main and Branch lodes. The former never contains more than 8 per cent. of palladium, while the latter contains anything from 20 to 40 per cent. of that metal. This difference in composition is well brought out by the following analyses by F. W. Watson and R. A. Cooper kindly placed at the writer's disposal by Dr E. T. Mellor. They are of platinum from the No. 3 or Termite Mound Winze on Welgevonden, No. 1772, and the No. 6 or Elephant Winze on Rietfontein, No. 3, which, as will be seen from Fig. 36, are only about 1100 feet apart.

	Welgevonden.	Rietfontein.
Pt	91.9	59.9
Pd	7.0	37.1
Au	0.4	3.0
Totals	<u>99.3</u>	<u>100.0</u>

Etching tests¹ on polished sections of the rich ore prove that the platinum is conspicuously zonal in structure, being made up of alternating layers of palladium-rich and palladium-poor platinum. The peculiar globular and reniform shapes of some of the platinum grains and their concentrically banded structure suggest the possibility of the platinum having been deposited from colloidal solution as a gel which only assumed a definite crystalline structure after deposition.

Distribution of the Platinum.—The distribution of the platinum in the lodes is extraordinarily erratic. The workable bodies of ore form irregular patches surrounded by barren lode matter. Such patches range up to 70 feet in length and up to 50 feet in vertical extent, but as a rule they are much smaller. Their horizontal dimensions are generally in excess of their vertical, so that it would not be correct to designate them

¹ Cf. Stanley, G. H., and Wagner, P. A. (39).

as ore-shoots. Within the limits of such patches specularite is a good indicator of high platinum values, the two minerals having evidently been deposited under the same physical conditions.

Some remarkably high assay values have been recorded. A picked specimen from the Elephant outcrop on Rietfontein, No. 3, assayed 3246 dwts. per short ton, equivalent to 0.55 per cent. A grab sample from the No. 6 Winze on Welgevonden returned no less than 3345.5 dwts. (0.57 per cent.) and another sample from the No. 3 paddock, Welgevonden, 2750 dwts. (0.47 per cent.). These are probably the highest platinum assays ever recorded. A 50-ft. stretch on the outcrop of the Branch Lode averaged 1019.5 dwts. over 35 inches, and a stretch of the same length on the Main Lode on Welgevonden, 107.5 dwts. over 20 inches. At a depth of 50 feet below the latter stretch a section of the lode 26 feet long averaged 270 dwts. over 60 inches. The highest assay recorded on the 100-ft. level was 274 dwts. to the short ton.

The Main and Branch lodes were systematically opened up over a distance of 1000 yards to depths ranging from 100 to 150 feet, and a plant for the treatment of the ore erected on the property. It was found, however, that the platinum metals were so patchy and erratic in their distribution and so difficult of extraction that their recovery did not pay. Operations were, therefore, suspended in August 1926, after the plant had been in operation for a few months. There are not wanting those who assert that, if work had been concentrated on the rich shoots and the money spent on the prematurely erected plant had been put into development, it might have been possible to open up a payable mine here.

Genesis of the Deposits.—The genesis of the Waterberg deposits presents a fascinating problem. The nature of the lodes, and the crustified vuggy character of the lode filling, point to their formation under relatively light load near the surface. The abundance of specularite points, on the other hand, to the vapours and solutions that deposited the ore minerals having had a fairly high temperature. We have thus evidently to do with a high temperature deposit formed near the surface. It is probable that, as in the case of many tin deposits, for example, there was an early pneumatolytic stage during which quartz, platinum, specularite, and pyrite

were deposited, and a later hydrothermal stage during which practically pure quartz and chalcedony were deposited from ascending heated waters. Hot springs still issuing in places along some of the faults may represent the final stage of the hydrothermal activity. The vapours and solutions evidently emanated from a body of igneous rock situated at no great depth, as it would otherwise be difficult to reconcile the high temperature character of the early mineralisation with the formation of the deposits near the surface. As to the nature of the igneous rock, the predominance of silica in the deposits suggests that it must have been of a persilicic nature. The abundance of chromiferous chlorite, an unusual mineral in quartz lodes, suggests, on the other hand, a basic or ultrabasic magma. It is possible, therefore, that the persilicic vapours and solutions that formed the lodes may have been the reaction residuum left over in the crystallisation of a basic or ultrabasic magma; and that the platinum metals extracted from this magma by "gas fluxing"¹ were concentrated in the persilicic extract.²

The only igneous rocks of post-Karoo age hitherto identified on the plateau tract of South Africa are the kimberlites and the nepheline basalts and limburgites of the Limpopo Valley.³ The last, according to Rogers, contain amygdaloids of pure quartz up to 7 inches across. These siliceous secretions illustrate the separation of persilicic rock from an ultrabasic magma. There is no reason for assuming, however, that there is any genetic relation between the limburgites and these Waterberg deposits.

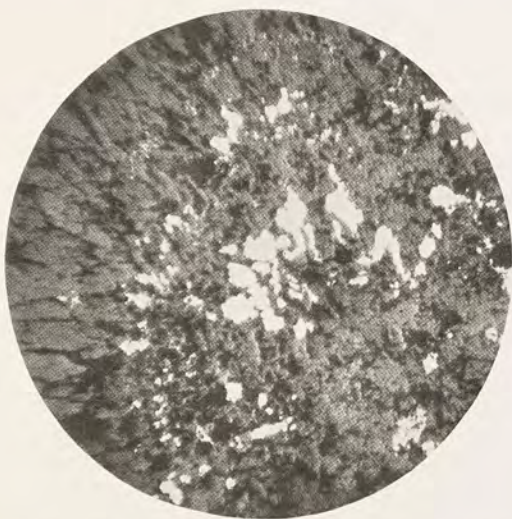
¹ Cf. Lindgren, W., *Econ. Geol.*, 1923, pp. 423-424; also cf. Wagner, P. A., *Econ. Geol.*, 1925, p. 283.

² Reference to the accompanying map (Plate XXXVI.) will show that if the Norite Zone of the Bushveld Complex is continuous between the northernmost points at which it is exposed in the Rustenburg and Potgietersrust districts respectively, it must underlie the area containing the Waterberg platinum lodes. This suggests the possibility of the platinum contained in these lodes having been extracted from the rocks of the Norite Zone by magmatic vapours and solutions emanating from a totally different source. To assume, as some writers have done, that the formation of the lodes is related to the intrusion of the Bushveld norite is to show a complete misunderstanding of the time relation between these two geological phenomena.

³ Cf. Rogers, A. W., "Notes on the North-eastern Part of the Zoutpansberg District," *Trans. Geol. Soc. S. Africa*, 1925.



1. The very rich Elephant Outcrop on the Branch Lode, Rietfontein, No. 3, Waterberg district, with Mr Adolph Erasmus, discoverer of the Waterberg platinum lodes.



2. Photomicrograph of polished section of rich ore from the Elephant Outcrop. Shows irregular grains of platinum (white) in a concentrically banded radial aggregate composed mainly of quartz crystals. Small flakes of specularite (grey) forming the narrow layer concentric with the outer platinum-rich layer are seen at the top of the photograph. $\times 16$.



As to the nature of the vehicle by which the platinum was transported we are in complete ignorance. Chlorine or fluorine at once suggest themselves, but no mineral containing either of these elements is present. It is just possible that it may have been water vapour in which the platinum was in colloidal suspension in the form of some compound such as hexahydroxyplatinic acid, $\text{PtH}_2(\text{OH})_6$; the shape and structure of many of the grains suggesting, as previously remarked, that the platinum was deposited as a gel. All this, however, is frankly speculative.

CHAPTER XX

ELUVIAL AND ALLUVIAL DEPOSITS

Lydenburg District.—The platinum-bearing dunites of the Lydenburg district have in proportion to their size given rise to fairly considerable deposits of platiniferous eluvium and rubble. These take the form of irregular sheets of surface detritus and soil covering the slopes and flanks of the hills on which the dunite outcrops. The biggest deposit is on Onverwacht, No. 330. Platinum is present in well-shaped crystals and in irregular grains and nuggety forms. Some of the eluvium has been found to carry as much as 70 dwts. per ton, but the bulk of it only carries a few pennyweights. The exploitation of this mineral, which should prove highly profitable, is to be undertaken in the near future.

There are less important deposits on Driekop, No. 170, Mooihoek, No. 147, and Hendricksplaats, No. 357.

Alluvial.—Notwithstanding the great extent and the wide distribution of the primary deposits, no really important alluvial deposits have so far been discovered in South Africa. For this there are three main reasons, namely :—

- (1) That the bulk of the platinum released by weathering from the primary deposits is in an extremely fine state of division.
- (2) That, owing to the practically continuous uplift of the land since early Tertiary times, all the main rivers draining the platinum fields have for vast periods of time been cutting downward with only brief temporary periods of aggradation.
- (3) That the rainfall over the area containing the platinum deposits is mainly in the form of torrential showers that cause the rivers to come down in spate, sweeping all the finer detritus supplied to them direct to the sea. Similar conditions have apparently prevailed for an immense period of time.

The most important alluvial deposits so far discovered are in the Lydenburg district.

Deposits of the Lydenburg District.—The most extensive occurrences are situated along the Steelpoort River, the biggest of them being situated below the road bridge near Fort Burger on the farms Leeuwvallei, No. 188, Steelpoort Drift, No. 350, and Aapiesdoorndraai, No. 162. It forms a terrace built of some 20 feet of sandy overburden overlying an unknown thickness of gravel composed almost entirely of rocks belonging to the Norite Zone. The gravel has been proved to carry platinum and a good deal of prospecting work has been done on it. So far, however, no considerable area of the gravels has been proved to be worthy of exploitation.

There are similar deposits in the western part of Leeuwvallei, No. 188, and at Kennedy's Vale, No. 253, and a fairly big patch of high-level gravel has been located on the farm Sterkfontein No. 187.

Patches of platiniferous alluvium along some of the normally dry watercourses draining the area are probably of quite recent formation, but the terrace and high-level gravels probably date back to Tertiary times.

Deposits in the Valley of the Olifants River.—Alluvial platinum, evidently derived from the denudation of the rocks of the Norite Zone of the Bushveld Complex, has also been found in the gravels of the Olifants River in the eastern and southern portions respectively of the Lydenburg and Leydsdorp districts. The deposits are of considerable extent but appear to be too poor to be worth working.

Deposits of the Potgietersrust District.—A promising stretch of platiniferous alluvium has been opened up on the Zwartspuit in the southern part of Zwartfontein, No. 121. It has a proved length of 600 yards and a width of 100 yards. The platinum is found beneath from 2.5 to 3 feet of sandy overburden in a layer of coarse grit carrying pebbles up to 2 inches across. In the pit where it is best exposed the platinum-bearing layer averages 6 inches in thickness and, judging by pannings, carries more than 1.5 dwts. of platinum per ton.

The Zwartspuit is tributary to the Magalakwin, along the course of which alluvial deposits should also be found.

Deposits of the Rustenburg of the Rustenburg District.—Small nuggets and worn crystals of platinum, up to 1.5 mm. across, and smaller grains of that metal have been found in the gravels and sands of the Magato Spruit on the farms Doorspruit, No. 878, and Klein Doornspruit, No. 255, situated in the Norite Zone of the Bushveld Complex to the north-north-west of Rustenburg; also in the small watercourse tributary to the Magato Spruit which crosses the farm Turffontein, No. 297. There do not appear to be any considerable accumulations of gravel on the farms named, but such exist along the Elands River into which the Magato Spruit discharges. They have not been tested so far.

Deposits of the Waterberg District.—Fairly extensive deposits of platiniferous alluvium have been located in the valley of the stream draining the area containing the platinum lodes on the farms Welgevonden, No. 1772, and Rietfontein, No. 3, in the Waterberg district. The biggest deposit underlies a terrace on the north side of the stream. It extends from Rietfontein, No. 3, across Diamant, No. 2245, into Rietvalley, No. 1438.

An unsuccessful attempt to work the deposits was made in 1925 by the Alluvial Platinums, Limited. Sections exposed in their workings show from 15 to 20 feet of clayey overburden overlying from 7 to 18 feet of gravel. The gravel carries small amounts of platinum in an extremely fine state of division.



1. View looking downstream from Road Bridge over the Steelpoort, showing alluvial terraces underlain by platinum-bearing gravel.



2. Section of platinum-bearing alluvium exposed on bank of Zwartspuit on Zwartfontein, No. 121, Potgietersrust Platinum Fields.



CHAPTER XXI

PLATINUM MINING AND ORE TREATMENT

WHILE alluvial platinum mining has been practised systematically in the Urals for over a century, platinum rock mining has so far been undertaken on a big scale only in South Africa, and that during only the past four years. A very considerable amount of work has already been done under the most diverse conditions, and much valuable information gained.

From the point of view of the mining engineer the several types of deposit described in the foregoing chapters fall into three main classes, namely:—

- (1) The small almost vertical dunite "pipes" of the Lydenburg district;
- (2) The big irregular steeply-dipping lenses of the Potgietersrust district; and
- (3) The relatively narrow and very extensive tabular ore bodies with low to moderate dips on the Merensky Horizon in the Rustenburg and Lydenburg districts.

1. The Dunite Occurrences.—These occurrences, the first to be opened up, presented some rather novel features to South African mining engineers, but suitable methods to deal with them were quickly evolved. From the surface to depths ranging from 30 to 80 feet the platinum-bearing dunite was broken in open quarries. For attacking the ore below this, three-compartment shafts were sunk well outside the possible areas of enrichment. From these shafts cross-cuts are driven at intervals of 100 feet to intersect the "pipes." From the cross-cuts levels are opened up and these in turn are connected by vertical development winzes sunk either within the "pipes" or just outside them.

For the extraction of the great cylindrical bodies of ore thus blocked out three different methods are in use, namely:—

(a) That employed on the Onverwacht Mine. Here, thin concrete "mats" or platforms are built across the "pipe" at

intervals of 50 feet, and the hortonolite-dunite between removed slice by slice by overhand stoping. To ensure the recovery of big metallics in the ore, bags are spread out on the floors of the stopes before blasting, and after blasting and the removal of the broken rock these bags are carefully shaken out.

As each "lift" or slice of the ore-body is stoped out, the excavated area is filled with waste rock tipped for this purpose through the development winze from the level above. As stoping proceeds, a timbered ore-pass is constructed through the filled area. Down this the broken ore is sent to the level below to be trammed to the main shaft and hoisted to the surface.

(b) Combined overhand and underhand stoping with square-set timbering, as employed at the Mooihoek Mine (Fig. 5). Eight-by-eight timbers are used. The cost of the square-setting works out at 1s. 8d. per ton of ore recovered.

(c) Shrinkage stoping with pillar support, as practised at the Driekop Mine. The ore at this mine, as we have seen, occurs in irregular patches, schlieren and veins separated by barren dunite. In mining, these areas of barren rock are left alone and constitute the supporting pillars. Provision has been made, however, for waste filling should this prove necessary.

Shrinkage stoping is probably the cheapest of the three methods.

Unfortunately, no complete costs are available except for the Mooihoek and Driekop mines jointly. These are given on page 278. They were kindly supplied to the writer by Mr G. Carleton Jones, with the approval of the Chairman of the local Board of the Lydenburg Platinum Areas, Limited. The costs are for the period ended 31st December 1928. During this period the average tonnage crushed monthly was 3475; about one-third of this being drawn from the Mooihoek Mine and the remainder from the Driekop Mine. It will be noted that the actual mining costs, including pumping, but excluding development, are only 6s. 9.4d. The total costs are much higher as, owing to the limited scale of operations, overhead charges are considerable.

(2) **The Potgietersrust Deposits.**—In the great composite lenses of the Potgietersrust fields, where stoping widths of from 20 to 50 feet have to be carried in ore-bodies dipping at from 50 degrees to 90 degrees, the *top-slicing* system of mining, with

concomitant waste filling is practised and has given excellent results. Levels are driven at intervals of 100 feet measured on the dip, and stoping proceeds upward along winzes or raises situated at the centre of the proved ore shoots.

Open quarrying has so far been resorted to only on the Zwartfontein Central ore-body, where there is a big open working 45 feet in depth (Plate XXI.1).

(3) **The Deposits on the Merensky Horizon** are, from the mining point of view, analogous to the Witwatersrand, and are to be worked on much the same lines as the Rand gold mines. Incline shafts are put down at regular intervals and then connected up with vertical shafts sunk at distances of 1000 to 2000 feet from the outcrop, depending on the dip of the "reef." From the incline shafts levels are driven at intervals again depending on the dip. On the Kroondal-Klipfontein Mine, where the dip is between 9 and 10 degrees, the interval between levels is 500 feet, and on Swartklip, north of the Pilandsberg, where the dip is 25 degrees, the interval is 160 feet. The levels are connected at distances of 500 feet by development winzes or raises, so that the ore is divided into great rectangular blocks 500 feet long and from 160 to 500 feet wide. Where the inclination of the "reef" is low the ore will be broken by breast stoping from these winzes. Where steep, underhand or overhand stoping will be practised.

Tests on a working scale have shown that the oxidised ore, which is soft and friable, can be easily and cheaply broken by means of pneumatic picks, and these will be extensively employed. It is estimated that mining costs in the oxidised ore will not exceed 4s. per ton.

In the harder sulphide ore recourse will have to be had to drilling by means of "jackhammers" followed by the usual blasting with dynamite. It has already been pointed out that, in the Rustenburg district, the workable platinum values are, in the sulphide zone, concentrated in a thickness of about 12 inches of the horizon, made up mainly of coarse feldspathic harzburgite and the thin Chrome Band under- or over-lying it. It is proposed to take full advantage of this concentration of the platinum metals in a narrow portion of the horizon by adopting resuing methods of mining, as it is obvious that the nearer the milling width can be kept to 12 inches, the higher will be the grade and recovery.

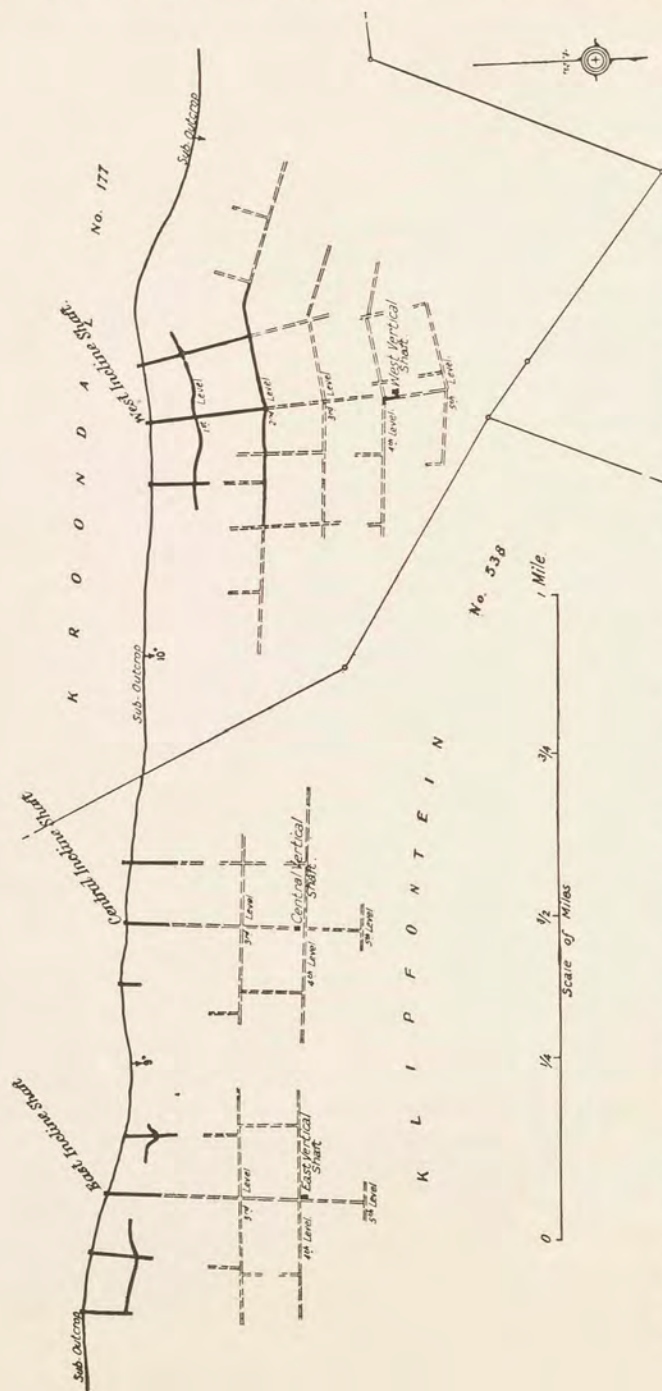


FIG. 37.—Plan showing Existing and Projected Underground Development on the Klipfontein-Kroondal Platinum Mines.

On the Kroondal-Klipfontein Mine where, as already stated, the Chrome Band and felspathic harzburgite in the sulphide zone overlie practically barren anorthositic norite, Mr G. H. Beatty, the Consulting Engineer, proposes in the first place to mine this barren footwall by holes drilled some two feet below the Chrome Band. These will break mainly barren footwall norite together with some Chrome Band. The broken rock will be carefully sorted underground and any fragments showing chromite sent to the mill. The rest will be packed to secure the hanging-wall. When a sufficiently large slice of the footwall has thus been removed, leaving an opening 2 feet high below the platinum-bearing part of the horizon, the overlying 12 inches of chromitite and harzburgite will be dropped by light blasts. All the material thus broken will be sent to the mill. It is estimated that the grade of the ore milled will not be less than 9 dwts. per ton.

At the Swartklip Mine, north of the Pilandsberg, where values are concentrated in the uppermost 12 inches of the horizon, the opposite procedure will be adopted. Here a narrow sector of the barren Merensky "Reef" overlying the Chrome Band will first be taken out, and the underlying 12 inches of rich ore subsequently broken by light blasts. In some sectors of the mine, however, where there is a well-defined parting in the Merensky "Reef" from 20 to 24 inches above the Chrome Band, it will probably be cheaper to carry within a stoping width of from 30 to 33 inches the 12 inches carrying the bulk of the platinum metals and from 17 to 21 inches of the overlying Merensky "Reef." As the Merensky "Reef" is of distinctive appearance and breaks in big rectangular blocks, there will be no difficulty in eliminating the bulk of it by sorting. Here, too, it is confidently anticipated that it will be possible to maintain a mill grade of at least 10 dwts.

As to costs, Mr Beatty estimates that, at the Kroondal-Klipfontein Mine, these will be £2 per square fathom, equivalent to roughly 10s. per ton. At Swartklip the estimated cost of mining and development is 11s. 6d. per ton mined.

The cost per ton milled will depend upon the ratio of the stoping width to the milling width. Assuming, for instance, that the stoping width is 30 inches and the milling width only 12 inches, it will be necessary to break, for every ton of ore sent to the mill, $2\frac{1}{2}$ tons of rock.

At 10s. per ton mined, the mining cost per ton milled will thus be of the order of 25s. It will actually be less than 25s. as only part of the ore mined will be sent to the surface.

At present one of the most difficult problems that has to be solved by the engineers of the several Rustenburg mines is: whether it will be more economical to treat the cheaply mined oxidised ore in which the platinum values are spread over a thickness of up to 30 inches, and from which only a relatively low extraction can be obtained, or the richer sulphide ore which will cost very much more to mine, owing to the concentration of values in a width of 12 inches, but from which, as we shall learn, an extraction of 80 per cent. of the platinum metals and of most of the nickel and copper present is assured.

A further point to be taken into consideration is that in the oxidised ore the ratio of platinum to palladium is from 10 to 11 per cent. higher than in the sulphide ore.

At present the sulphide ore is favoured. Perhaps the most satisfactory solution will be to compromise by treating a mixture of the two classes of ore.

Ore Dressing and Metallurgy.

As a result of the opening up in 1925 of the different platinum deposits of the Bushveld Complex in which the metal occurs in the most diverse conditions and associations, South African metallurgists found themselves face to face with an entirely new set of problems.¹

It is a pleasure to be able to record that they rose to the occasion and that we have at present satisfactory processes for treating all the different classes of ore and obtaining marketable products from them. This latter is a most important consideration, the whole position being dominated by the fact that platinum refiners will not buy concentrate containing less than 60 per cent. of platinum metals.

Treatment of the Ores of the Dunite Deposits.—Attention was first directed to the rich hortonolite-dunite deposits of the Lydenburg district. Here, as already explained, the bulk of the platinum, in the oxidised zone at least, occurs in the metallic state. Simple gravity concentration thus naturally commended itself as the obvious method of treatment. It was

¹ Previous to this a process for treating the ores of the Waterberg district had been evolved.

found, however, that, while the crushed dunite was readily amenable to concentration, the resulting concentrate was of a very low grade. Thus, tests made on a bulk sample of the ore of the Onverwacht Mine, using gravity stamps in conjunction with curvilinear and corduroy tables, indicated that an extraction of 83 per cent. of the platinum present could be obtained in a concentrate representing about 1.7 per cent. of the original ore and assaying 600 dwts. to the ton.¹ Now 600 dwts. is only 0.1 per cent. against the 60 per cent. minimum required by refiners. The concentrate was thus quite unsaleable.

Efforts were therefore directed toward obtaining a richer product. At the Onverwacht Mine this was accomplished by the extensive use of traps for metallics and the treatment of the gravity concentrates by amalgamation, using certain activating reagents, as platinum, unlike gold, does not amalgamate directly on mercury being brought into contact with it.

At the Maandagshoek plant of the Lydenburg Platinum Areas, Limited, almost equally good results have been achieved by reconcentration combined with acid treatment, and part of the platinum is here recovered by flotation.

The Onverwacht Plant and Process.—The Onverwacht plant and process may first be described; what follows being largely based on the excellent paper of Prentice and Murdoch, already quoted.

The plant, which has a capacity of 100 tons per diem, is situated on a hill-side adjacent to the mine (Plate IX.2), in such a position that the ore can be trucked by natives along a level track from the shaft bins to the crusher.

Primary crushing is accomplished by means of a 20 by 10 inch Blake crusher which delivers by means of a belt conveyor to the bins of a battery of ten 1450-lb. Californian stamps, crushing through a 9-mesh screen.

The pulp from the stamps passes via a trap for catching metallics to the cone of a ball tube-mill measuring 5 feet by 4 feet 4 inches. The cone underflow passes over a trap and through the tube-mill and then via a long sluice-box-trap to four primary Wilfley tables. The cone overflow is further classified in a similar cone, the underflow joining the tube-mill outlet and the overflow passing to two James slime tables, and thence via

¹ Cf. Prentice, T. K., and Murdoch, R. (93).

two corduroy tables to the tailings dam. The middlings from the primary Wilfley tables are elevated to a thickening cone, the underflow passing through a 5-ft. Wheeler pan before joining the overflow, which is then dressed on three tables, two being Wilfleys and the third a James sand table. The tailings therefrom join the primary Wilfley tailings and pass over sand corduroy tables before being discharged to the dam. A double sided dipper wheel is installed to elevate the primary middlings of the Wheeler pan cone, and the Wheeler pan discharges to the secondary tables. Apart from this the whole of the flow is by gravity.

The concentrate from the various traps and the die-sands, which together yield 65 per cent. of the total platinum recovered, are redressed on James and curvilinear tables. The metallics from the tables are hand-panned and then treated successively with 10 per cent. H_2SO_4 and 10 per cent. HNO_3 . Thereafter they are washed, dried and weighed, and despatched as "Coarse Crude Platinum," this product assaying about 82 per cent. of platinum group metals.

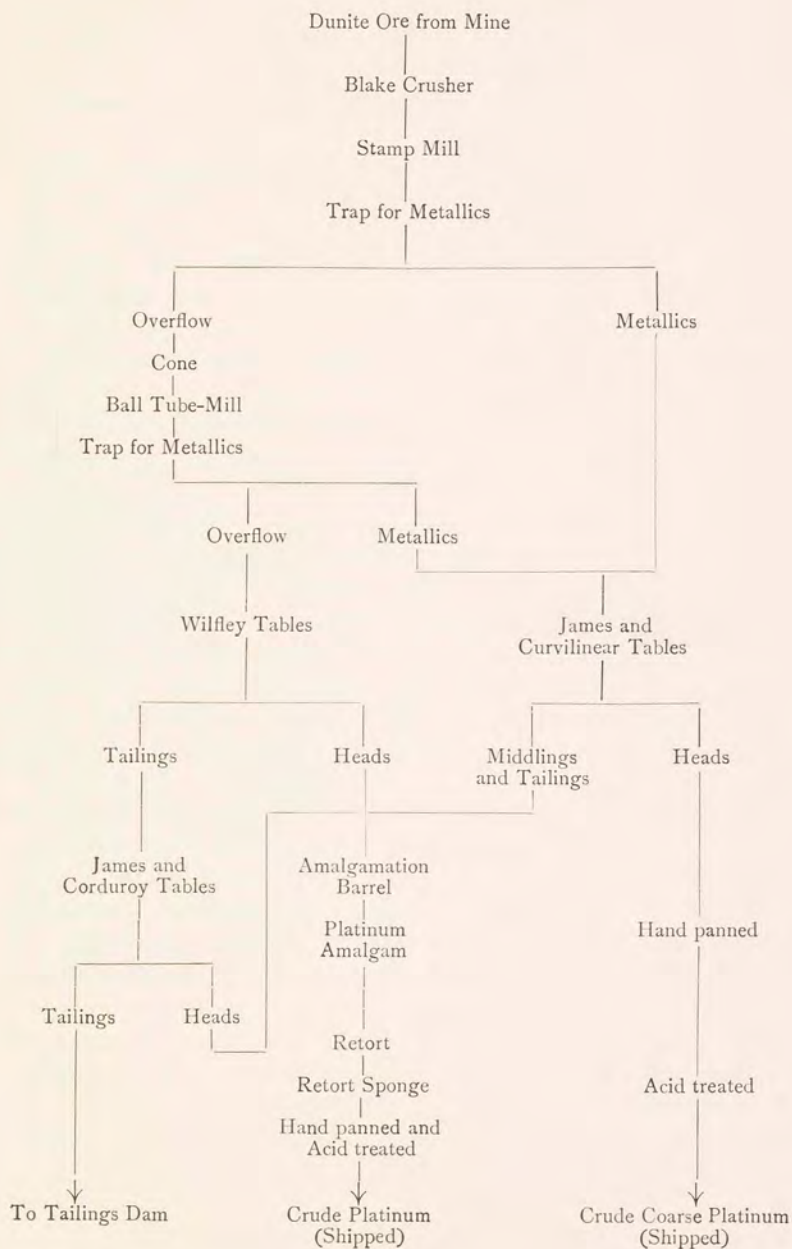
The concentrates of the primary and secondary Wilfleys and of the James and corduroy tables are treated in lots of 1000 lb. in a revolving amalgamating barrel, the amalgamation of the platinum being promoted by activating agents in the form of zinc amalgam, copper sulphate and sulphuric acid. The barrel is revolved for two hours and then discharged via batea amalgamation plant and curvilinear table.

The dirty amalgam obtained is re-amalgamated for half an hour with zinc amalgam, copper sulphate and sulphuric acid. Thus cleaned it is now pressed and treated in earthenware jars with dilute sulphuric acid to remove zinc and iron. After this has been accomplished it is retorted in small pot retorts. The retort sponge, after being subjected to further panning, sorting and acid treatment, is washed and dried, giving a product assaying about 70 per cent. of platinum group metals, which is shipped.

The recovery by amalgamation is about 98 per cent. and the all-over recovery of the plant ranges from 82 to 85.56 per cent.

The following skeleton flow-sheet will render clear the course of the rather complicated treatment. Detailed flow-sheets accompany the paper of Prentice and Murdoch, already quoted.

Skeleton Flow Sheet, Onverwacht Plant.



No figures in regard to the costs of treatment at this plant are available, but during the quarter ended 31st December 1928, the total operating costs at the Onverwacht Mine, including mining, treatment and administration, were 32s. 1d. per ton.

Up to the end of 1928 it had produced 21,820 ounces of platinum metals.

The Maandagshoek Plant.—The platinum-bearing dunite of the Mooihoek and Driekop Mines is treated at the Maandagshoek plant,¹ situated on the farm of that name which lies between Mooihoek and Driekop. The plant is connected by independent aerial ropeways to the mines, that to Mooihoek being $3\frac{1}{4}$ and that to Driekop $3\frac{3}{4}$ miles in length. The ore is conveyed in skips of 350 lb. capacity.

The plant is situated on the slopes of a steep hill (Plate XI.2), on benches cut out of solid norite. Originally designed for 100 tons per diem, it is at present treating an average of 135 tons.

On arrival at the plant the ore is tipped into a big storage bin. From this it is conveyed to a 24 by 13 in. Hadfield jaw-crusher the discharge from which is trommelled. The oversize is conveyed to a 24-in. disc-crusher which discharges to a conveyor serving the mill bin. Fines from the trommel below the jaw-crusher pass direct to this conveyor. Secondary crushing is done in two 7 ft. by 5 ft. 6 in. ball-mills using forged steel balls, the resultant pulp being passed over ten No. 6 Fraser and Chalmers concentrating tables. The "heads" from these are transferred by hand to the clean-up room storage bin for the extraction of metallics, and the "tails" are elevated by a 4-in. sands pump to Dorr 7-ft. bowl classifiers which return the underflow to the ball-mill feed for regrinding, the overflow being laundered to two 20-ft. Dorr thickeners.

The thickened pulp flows over corduroy tables and thence to a sub-aeration flotation unit. The table heads and corduroy concentrates are treated in the clean-up room on James sand and slimes tables respectively for extraction of the metallics. These are acid cleaned to remove most of the insoluble impurities and, when finally prepared for despatch, assay about 60 per cent. of platinum group metals.

¹ A good description of this plant is given in the *Mining and Industrial Magazine of Southern Africa*, of 22nd Aug. 1928, pp. 585-586.

The analysis of a representative batch of metallics was actually as follows:—

	Assay Value, Per Cent.
Pt	59.73
Pd	0.75
Ir	0.12
Rh	0.41
Osmiridium	0.25
Total	61.26
Gangue and other impurities (by difference) .	38.74
Total	<u>100.00</u>

The redressing operations on the James and slimes tables also produce "middlings" too rich in platinum to be returned to the ordinary circuit and too poor to be acceptable to refiners. This rich product, which assays over 17 ounces per ton, is shipped to England for further treatment.

The product of the flotation plant is collected in settling bins, dried, packed in drums and then also shipped to England for further treatment. It assays 7.45 ounces of platinum metals per ton.

The over-all extraction at the Maandagshoek plant is 82.1 per cent., of which approximately 74.63 per cent. is contained in the metallics, 3.53 per cent. in the rich gravity concentrate and 3.94 per cent. in the flotation concentrate.

From 16th August 1926, when it was started, to the end of the last financial year at 30th June 1928, the plant had produced 9498 ounces of platinum metals in the form of metallics, 27.50 tons of rich gravity concentrate (middlings) containing 478 ounces of platinum metals, and 87.02 tons of flotation concentrate containing 648 ounces of platinum metals.

The plant is at present producing an average of some 750 ounces of platinum metals per month. It operates very economically. Thus, for the six months ended 31st December 1928, the combined costs of mining at the Mooihoek and Driekop mines and of the ore treatment and administrative expenses was 24s. 3.2d. per ton milled. This total was made up as shown in table on page 278.

		Per Ton Milled.	
		S.	D.
Mining		5	11.6
		S.	D.
Stoping		2	1.1
Timbering and Packing		1	1.1
Hoisting		0	10.9
Tramming and Shovelling		1	10.5
Pumping and Baling		0	9.8
Transport of Ore to Mill		1	4.8
Milling and Concentration		7	9.1
Mine Office Expenses		0	9.3
General Mine Expenses		3	5.0
Claim Licenses		0	6.5
Development		3	7.1
Total Mine Working Cost		24	3.2

It should be stated that during the period under review the average tonnage crushed monthly was 3475, about one-third of this tonnage being drawn from Mooihoek and the remainder from Driekop.

Platinum realisation charges during the same period amounted to 6.45 pence per ton milled.

Treatment of the Ores of the Merensky Horizon.—The treatment of these ores proved to be far more difficult than that of the dunitic ores, and entirely satisfactory methods of treatment have only comparatively recently been evolved.

Simple gravity concentration and ore flotation were early tried, but both proved unsatisfactory as they yielded bulky low-grade unsaleable concentrates.

Efforts were therefore here too directed to the retreatment of these preliminary concentrates with a view to enriching them. Attention was specially devoted to the sulphide ores, as they had proved themselves to be very readily amenable to the flotation treatment. Actually it was found that by flotation 90 per cent. of the platinum metals and of the nickel and copper present could be recovered in a concentrate containing from 6 to 8 ounces of platinum metals.

In the case of the oxidised ore the recovery of the platinum metals was only between 65 and 70 per cent. and practically all the nickel and copper were lost.

The simplest way of enriching the sulphide concentrate is to smelt it to a matte, and this forms the basis of what will

here be referred to as the Krupp Process, the development of which is due largely to Dr P. Trotzig. It consists, briefly, in smelting the sulphidic flotation concentrate to a low-grade nickel-copper-iron matte, and then resmelting this matte to produce a higher-grade matte containing roughly

25.5 per cent. of Nickel
15.5 " " Copper
65 ounces per ton of Platinum Metals.

This enriched matte is then roasted and leached with sulphuric acid. The leaching dissolves the nickel, copper and iron which can be reprecipitated, leaving a rich sludge from which, by smelting, there can be obtained a product containing 60 per cent. of platinum group metals.

Using sulphide ore alone, the Krupp process gives an all-over extraction of 85 per cent. of the platinum metals and 80 per cent. of the nickel and copper contained in the ore. Using two-thirds sulphide and one-third oxidised ore, the all-over extraction of platinum metals is 78 per cent.

The process of the Chemical and Metallurgical Corporation, Limited, of which a good deal has been heard of late, appears to be practically identical with the Krupp process, except that provision is made for the necessary bessemerising of the enriched matte before roasting and leaching.

The Chlorination Process.

Working on entirely different lines in the Rand Mines Laboratory of Johannesburg, the Chief Metallurgist of the Rand Mines, Limited, Mr K. L. Graham, and his associates, R. A. Cooper and F. W. Watson, have evolved a process that is considered in some quarters to be even more satisfactory. This is known as the Chlorination Process, chlorine being the principal agent involved. The process is again carried out in stages. The sulphidic concentrate obtained from the platinum ores by flotation is dried and then roasted for approximately six hours at a dull red heat to eliminate sulphur and oxidise thoroughly all base metals. After withdrawal from the roasting furnace the concentrate is mixed with salt and is then placed in the chlorination furnace where it is maintained at a temperature of between 500° and 600° C. for about five hours.

During this period chlorine is passed over the surface of the heated material, which is not disturbed in any way during the treatment.

This chlorination converts the platinum group metals and the copper and nickel present in the concentrate into chlorides readily soluble in acidified water.

On withdrawal of the material from the chlorination furnace it is dropped into acidified water and the solution containing the platinum metals, nickel and copper is separated by washing from the insoluble residue. The solution obtained is next agitated with powdered limestone which precipitates copper in the form of a green carbonate. The copper precipitated, which contains only a minute quantity of platinum, is removed by filtration. The copper and platinum present in it are easily recovered by smelting and electrolysis.

The platinum metals are then precipitated from the solution as a black powder by agitation with zinc dust, and this powder is separated by filtration. The black precipitate is dried and roasted to a red heat for a few minutes and is then ready for the refiners, as it contains over 70 per cent. of platinum group metals. From the residual solution nickel is precipitated by known methods such as treatment with caustic soda or bleaching powder.

The insoluble residue remaining after the chlorination treatment and washing, as described above, is cyanided in the usual way to recover its gold content, the gold being unattacked by chlorine in the chlorination furnace as the temperature of treatment is above the dissociation temperature of gold chloride. By this cyanidation an additional 4 to 5 per cent. of platinum group metals are also recovered.

Exhaustive tests on a working scale have demonstrated that by the combined chlorination and cyanide process approximately 90 per cent. of the platinum metals and gold content of the flotation concentrate can be extracted, this being equivalent to an over-all extraction of from 75 to 80 per cent. It is of interest to record that in this process there is a marked preferential recovery of platinum, with the result that roughly 90 per cent. of the platinum contained in the concentrate is extracted, equivalent to about 80 per cent. of the platinum content of the original ore.

It is estimated that, working on a big scale, the cost of treating concentrates by the chlorination process will be approximately £7 per ton.

The Johnson Matthey Process.

Another process for treating the concentrates of the Merensky Platinum Horizon, details of which are not as yet available, has been evolved by the well-known firm of Johnson Matthey, Ltd., London. An extraction of from 95 to 97 per cent. is claimed, and the cost per ton of concentrate is estimated at £10.

The Process to be Adopted.—Which of these processes is to be adopted by the Potgietersrust Platinums, Limited, in their plant now being erected near Rustenburg, has not as yet been decided, but it is confidently predicted that, using any of them, it will be possible to produce platinum at from £5 to £7, 10s. per ounce.

The Eklund Process.

Apart from these processes in which the ore is dealt with in stages, there has been patented a direct electrolytic amalgamation process which bears the name of its inventor, Mr John Eklund. It is applicable to oxidised and sulphide platinum ores and permits the recovery of the platinum metals directly from their ores without preliminary concentration, though it is also applicable to concentrates. It consists in bringing the comminuted ore into contact with zinc amalgam in the presence of an activator, the platinum metals being thereby amalgamated and retained by the amalgam. The zinc amalgam is preferably applied to an iron or nickel surface.

The activator which has been found to be most generally useful is an aqueous solution containing mercuric chloride, zinc chloride, hydrochloric acid and chlorine, with or without the addition of sodium chloride.

The ore is crushed to about 200 mesh in a solution which has already passed through the process and contains these activators. A small quantity of hydrochloric acid is then added to the pulp and this acidified pulp passed over an iron or nickel surface coated with zinc amalgam which retains the precious metals; the amalgam being then retorted in the ordinary way. It is found to be desirable to have a relatively

long period of contact between the crushed ore and the activator solution before the pulp is passed over the amalgam. In the case of platinum ores thirty minutes to one hour is required. After this the actual amalgamation takes place rapidly in a period ranging from 15 to 60 seconds. Tests by this process on ores from the Kroondal-Klipfontein Mine, near Rustenburg, showed an extraction of from 76 to 78 per cent. Other tests, however, were not equally satisfactory, and it appears doubtful whether the average percentage extraction by this process will be anything like as high as that by the processes already dealt with.

**The Pilot Plant of the Potgietersrust Platinums, Limited,
near Potgietersrust.**

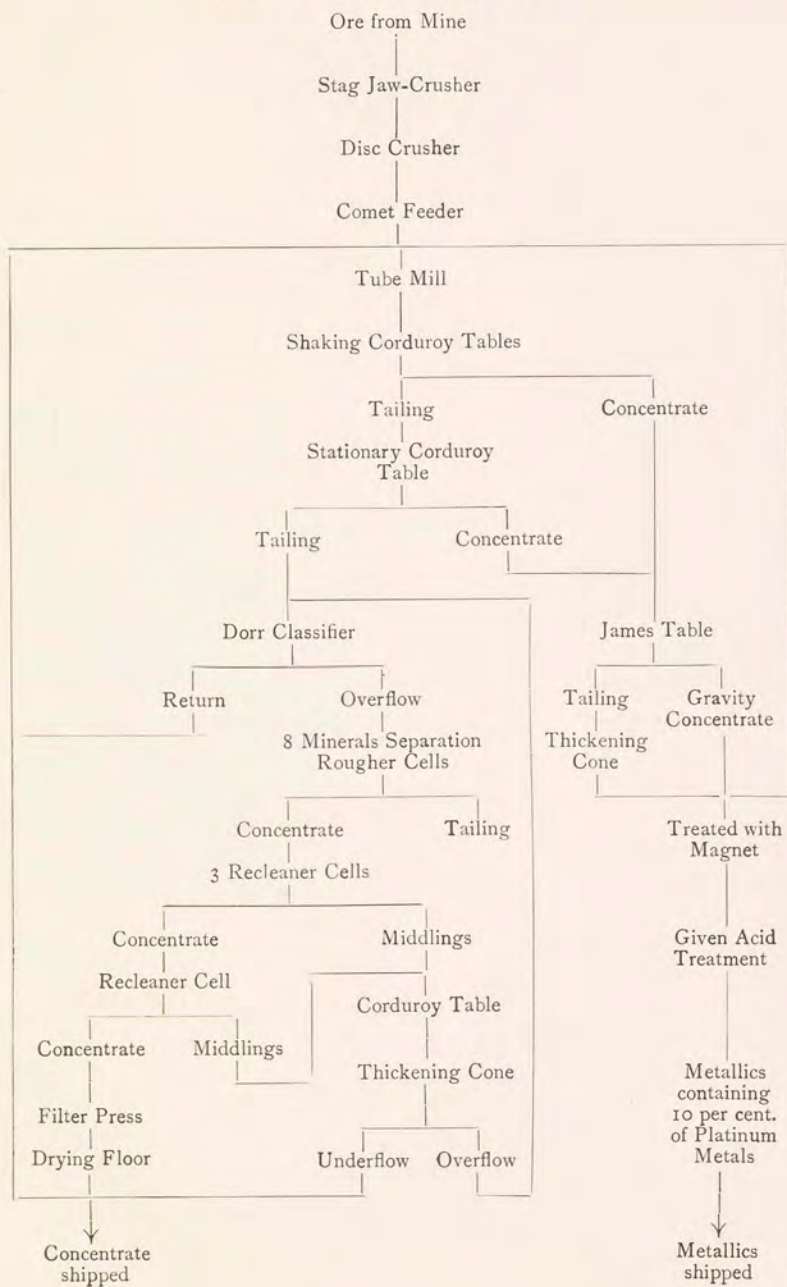
A brief description may finally be given of this plant which was erected on Zwartfontein, north-north-west of Potgietersrust, in 1927, and has been in continuous operation ever since.

Originally intended as a flotation plant pure and simple, it has been modified by the addition of corduroy, shaking corduroy and James tables, and is now actually producing a saleable gravity concentrate in addition to a flotation concentrate which is shipped overseas for further treatment. The plant is at present treating a mixture of oxidised and sulphidic magmatic and contact metasomatic ores from the Zwartfontein Central Sector, the proportion of oxidised to sulphide ore being approximately 2 : 1.

It has already been pointed out that the platinum metals and minerals in the Potgietersrust ores are in a much coarser state of division than in the ores of the Merensky Horizon as developed in the Rustenburg district. This explains the particular treatment adopted, which would not be applicable without considerable modification to the Rustenburg ores.

The crushing equipment consists of a Stag jaw-crusher, said to crush to from $1\frac{1}{2}$ to $2\frac{1}{2}$ inches, a disc crusher, said to crush to from $\frac{1}{2}$ to 1 inch, and a 22 ft. by 5 ft. tube-mill fed by a Comet feeder. The concentrating appliances include shaking and stationary tables, a James table and "rougher," and "cleaner" and "recleaner" Minerals Separation flotation cells. The metallics caught on the corduroy tables are retreated on a James table. The "heads" from the latter are treated with a magnet and are then given an acid treatment, the final

Flow Sheet, Potgietersrust Plant.



product assaying over 60 per cent. of platinum group metals. Roughly 30 per cent. of the platinum present in the ore is contained in these metallics which are shipped. The flotation concentrate, which is shipped, represents 0.8 per cent. by weight of the ore fed into the plant. The course of the treatment is indicated on the flow sheet on page 283.

Up to 4th December 1928, the plant had produced 1110 tons of concentrate estimated to contain—

4726	ounces of platinum,
4775	„ „ palladium,
209	„ „ other platinum group metals and gold,

and a fairly considerable tonnage of nickel and copper.

The output of the plant is steadily increasing and, during the last quarter of 1928, there was produced, as already stated, concentrate containing 1045 ounces of platinum and 796 ounces of palladium.

Treatment of Rhodesian Platinum Ores.—A small concentrating plant (Plate XXXIII.2) was erected in 1927 at the Wedza Platinum Mine, belonging to Messrs Granger Brothers, of which a description has already been given.

The plant consists of a Hardinge mill, classifier, cement strakes, Frue vanner and curvilinear shaking table.

The product of the Hardinge mill, after being classified, goes to long cement strakes. The concentrate here collected is fed on to the Frue vanner which discharges on to the curvilinear table. The concentrate made by the latter assayed from 100 to 130 ounces of platinum metals per ton, the bulk of the platinum being, as previously stated, in the form of sperrylite.

The plant, which the writer understands operated cheaply and efficiently, was run for some months. As, however, there was no sale for the concentrate, and refiners demanded an exorbitant price for its further treatment, operations were suspended early in 1929, since when the plant has been idle.

CHAPTER XXII

THE PRESENT POSITION AND PROSPECTS OF THE SOUTH AFRICAN PLATINUM INDUSTRY

THAT the South African platinum industry has so far disappointed the more sanguine hopes, originally entertained of it, is undeniable. While it was freely prophesied that by the end of 1928 platinum production from the mines on the Merensky Horizon would be in full swing, it is probable now that it will be well into 1930 before there is a really big output from that source. Delay of this kind, however, is inevitable in starting up a new industry under totally new conditions, and, taking everything into consideration, South African mining engineers and metallurgists have every reason to be proud of what has already been achieved.

Nor has the delay been without its compensations. Partly due to it there has, as we shall learn, been a natural weeding out process of all but comparatively few of the more promising of the numerous companies originally floated. The industry is thus at present in a much sounder position than it has been since its inception.

It has already been shown that the ore-reserves¹ on the Merensky Horizon in the Rustenburg district are almost unlimited. The reserves in the three known workable dunite deposits are, on the other hand, comparatively very small. Actually the position in regard to the dunite occurrences is as follows.

The Onverwacht Mine will probably be able to maintain an average monthly output of about 400 ounces up to the end of the year when it will be worked out, unless some entirely new strike is made.

The Mooihoek and Driekop mines, belonging to the

¹ The term "ore-reserves" as used in the present chapter must be taken by mining engineers to be synonymous with "possible" or "prospective" ore.

Lydenburg Platinum Areas, Limited, are in a better position, and should be able to maintain their present output of between 600 and 700 ounces per month for at least five years.

With regard to the Merensky Horizon five companies, all of them more or less equally favourably circumstanced, are actively developing mines in the Rustenburg and Potgietersrust districts. They are:—

(1) *The Potgietersrust Platinum, Limited*, who are conducting operations in the Potgietersrust and Rustenburg districts. In the former they are operating the Zwartfontein Central Mine and the treatment plant already described.

The present output is approximately 4000 ounces of platinum and palladium per annum, and this output can be maintained indefinitely. At the present time some 300,000 tons of payable ore are actually blocked out ready for stoping above the 100-ft. level.

The Potgietersrust deposits are much wider than those on the Merensky Horizon in the Rustenburg district, but, owing to the occurrence of the ore in irregular shoots they will probably prove to be more difficult and expensive to work.

In the Rustenburg district the company are actively developing the Kroondal-Klipfontein Mine and are erecting a treatment plant on the property. It is estimated that there are in this mine some 3,000,000 tons of workable oxidised ore, the tonnage being estimated over a milling width of only 12 inches; and many times this tonnage of sulphide ore. The development at present in hand will block out a very big tonnage of both oxidised and sulphide ore.

The plant, in process of erection, is designed to produce 28,000 ounces of platinum metals per annum. It is expected to be in commission by the end of 1929.

(2) *The Waterval (Rustenburg) Platinum Mining Company, Limited*, who are developing a very promising mine on the farm Waterval, adjoining the Rustenburg Town Lands. The total reserve of ore on the Mynpacht and Discovery claims is estimated at nearly 20,000,000 short tons. A treatment plant with a capacity of 10,000 tons of ore per month is being erected.

(3) *The Platinum Exploration Company, Limited*, who are conducting operations on Swartklip, No. 989, situated 52 miles

north-by-west of Rustenburg. The farm is estimated to contain recoverable reserves of ore of the order of 24,000,000 tons. A very considerable tonnage of oxidised and sulphide ore has been opened up, and recent developments at depth have disclosed exceptionally high values. A treatment plant with a capacity of 250 tons of ore per diem is being erected, and should be producing by the middle of 1930.

(4) *The Elandsfontein Platinum, Limited*, who have opened up a promising mine on the farm Elandsfontein, No. 820, situated 65 miles north-north-east of Rustenburg, and are contemplating the erection of a treatment plant with a capacity of 250 tons per diem.

(5) *The Transvaal Consolidated Land and Exploration Company, Limited*, who are developing mines on Brakspruit, No. 393, situated east-south-east of Rustenburg, and Bosch-koppie, No. 685, situated north-west of Rustenburg. Both are said to be opening up very well.

It should also be stated that the *Colonial Mining Development Company, Limited*, are opening up what is claimed to be a promising stretch of the Merensky Horizon on the farm Roodekopjes, No. 171, south of Marikana Station.

Assuming that only the four first-named companies proceed with their construction programmes, there will be in existence before the end of 1930 four plants, each capable of producing over 25,000 ounces of platinum metals per annum, in addition to the Potgietersrust plant of the *Potgietersrust Platinum, Limited*, producing 4000 ounces per annum, and the Maandagshoek plant of the *Lydenburg Platinum Areas, Limited*, producing some 8000 ounces per annum.

South Africa will thus actually be producing, or at least in a position to produce, platinum metals at the rate of well over 100,000 ounces per annum, as against about 17,000 ounces at the present time. There can be no question, moreover, that if these companies achieve success, others will follow with the erection of treatment plants. And, so far as reserves are concerned, it is quite safe to say that South Africa could furnish a very much greater output for an indefinite period.

Two very important questions naturally arise: how much South African platinum can the world absorb, and at what price?

To these questions in the present state of our knowledge

no definite answers can be given, but it will be interesting and useful to discuss the principal factors which they involve. They are:—

(a) **The Amount that the World is Prepared to Spend Annually on the Purchase of Platinum.**

In the year 1912 the world's production of "new" platinum, according to G. F. Kunz,¹ was 279,036 ounces. The corresponding figure for 1913 was 229,315 ounces.

The average annual production for these two years was thus 254,175 ounces.

The average London price during 1912 and 1913, as we have seen, was £9 per ounce troy; so that during this period the world spent an average of £2,228,757 per annum on platinum.

The production during 1926 was 167,500 ounces, and the average price £23, 7s. per ounce, making a total amount expended on platinum during the year of £3,911,125.

The estimated production for 1927 is 175,000 ounces, and the average price £16 per ounce, making a total of £2,800,000.

The production for 1928 appears to have been somewhat higher, but the average price less.

At first sight it would appear from the figures given that much more was spent on platinum during 1926-27 than in the years before the Great War. Actually this is not so, as the decrease in the purchasing power of gold has to be taken into consideration.

According to the annual Index-Numbers published by the *Statist*, the 1926 index-number, taking the average of the 1912-13 wholesale price index as 100, is 148.2; and the 1927 index-number is 143.5.²

Dividing the amount spent on platinum in 1926 by 1.482, we get £2,639,085, and dividing the amount spent in 1927 by 1.435, we get £1,951,220. These sums represent the amount actually spent on platinum on the basis of the 1912-13 gold values.

Their total, namely, £4,590,305, is almost exactly equal to the total for 1912 and 1913, namely, £4,457,514.

¹ *The Mineral Industry during 1913*, New York.

² The writer is indebted for these figures to Dr S. Herbert Frankel, head of the Department of Economics, University of the Witwatersrand.

From preliminary estimates to hand the 1928 figures are similar to those for 1927.

It would appear, therefore, that, allowing for inevitable fluctuations due to one cause or another, the world is spending just about the same amount on platinum at the present time as before the war, taking the actual purchasing power of gold as a basis.

The important point is that the world is getting very much less platinum in return, the present price being round about £13, 10s. per ounce as against the pre-war figure of £9. This increase in price has had one very important effect, namely, of putting platinum in the category of the luxury metals. Before the war the greater part of the production, which, as we have seen, was then much higher than at present, went into chemical and technical uses. The gradually increasing scarcity and consequent increase in price due to the war gave a great impetus to the development of platinum substitutes for the purposes named. These proved so successful that the need for platinum was in many cases eliminated altogether, and what was once the largest field of consumption for platinum metals is at present one of the smallest. On the other hand, there has been an enormous increase in the demand for platinum for jewellery, which now absorbs roughly 70 per cent. of the total supply. The ever-growing popularity of the metal for this purpose is due partly to its high price, and jewellers actually maintain that consumption would be increased if higher prices prevailed.

This view is shared in other quarters, and some authorities maintain that consumption would not be increased very materially even if prices were considerably reduced; platinum, according to a recent writer in *Commerce Monthly*,¹ being one of the few commodities that does not conform to the axiom that a high level of prices tends to check and a low level to stimulate consumption. To this subject we shall revert later.

(b) Marketing Conditions.

Up to the year 1903, the sales and price of platinum were largely controlled by the London firm of Johnson Matthey, Ltd.

About this time, however, a French Company, *Société*

¹ February 1929.

Anonyme d'Industrie du Platine, began to occupy a dominating position in the platinum industry. It erected its own refinery at St Denis, near Paris, and formed a syndicate for the control of the price of the metal, in which Messrs Johnson Matthey, Ltd., and other powerful firms were interested. It was the syndicate that stabilised the price round about £9 per ounce in the years preceding the Great War.

During the war this international selling organisation was dissolved, but soon after the Armistice another powerful syndicate was formed to take its place. It is composed of Messrs Johnson Matthey, Ltd., London; Baker of New York; Heraeus of Hanau; and Maret and Bonnin of Paris; the three first-named firms having also been members of the original French syndicate. Up to March 1927 the market was largely controlled by the syndicate, which allotted quotas to each of the big producers and purchased their quotas at prices agreed upon, on condition that no platinum was sold directly to outside buyers. The quota allotted to the Soviet Government for 1927 was between 60,000 and 70,000 ounces, at the then price of £22 per ounce. As, however, the Uralian production for the year was estimated at 100,000 ounces, the Soviet representatives demanded a larger allotment, whereas the syndicate, in view of increased production elsewhere, considered that even the quota they had given them was too high and desired to reduce it. In consequence the agreement was not renewed and the Soviet output was put on the market in direct competition with the syndicate; the *Rusplatina*, an organisation in which the monopoly for the exploitation of the Ural platinum deposits is vested, having for this purpose called into being a selling organisation, the *Edelmetalle-Vertriebs Aktiengesellschaft*, with headquarters in Berlin and branches in London and New York.

As a result of the activities of this agency an amount of platinum considerably in excess of the quota previously allotted by the syndicate was sold by the *Rusplatina* by the end of the year, but at a much reduced price; the breaking away from the syndicate of that organisation having led to a sharp drop in the price of the metal from £22 per ounce, in January 1927, to £13, 10s. in July of that year. The net result was that the amount realised was practically the same as if the original quota had been sold at the higher price. The fall in price, moreover,

found no favour in the trade generally where it is claimed that it led to a lessened demand for platinum.

Since then the price of platinum has remained at much the same level.

(c) **Relative Cost of Production in Russia, Colombia
and South Africa.**

It has been shown that an output round about 175,000 ounces of "new" platinum per annum is all that the world can at present absorb, and that it is at least doubtful whether lowering the present price of about £13, 10s. would result in any greatly increased demand.

This means that any increase in the South African production must be either at the expense of producers in other territories, or must follow increased demand from entirely new uses or the replacement of substitutes.

As to the first alternative, this will obviously depend upon the ability of South Africa to produce platinum on a big scale at a price that will enable her to undersell her principal competitors, Russia and Colombia.

According to information from a very reliable source, the cost of production on the Uralian fields, owing to overstaffing and inefficient management, ranges from £10 to £12 per ounce, and platinum cannot be produced economically under the former figure.¹ Colombian costs are apparently much the same as in the Urals, and here too, if our information be correct, platinum cannot be produced economically under existing conditions at less than £10 per ounce.

With regard to South Africa, actual costs of production are so far only available for the Onverwacht and Mooihoek-Driekop mines in the Lydenburg district, working on dunite ores.

At Onverwacht the cost per ounce, month by month, exclusive of administrative expenses, directors' fees and Government taxes, has fluctuated from £3, 9s. 11d. when treating high-grade ore to £10, 4s. 9d. when treating low-grade ore.

For the year ended 30th June 1928, the cost per ounce, exclusive of these overhead charges, was: £6, 18s. 9d.

Including them, it was: £7, 5s. 10d.

At the Mooihoek-Driekop Mine, the cost per ounce for the

¹ Except perhaps by the *Starateli* to be presently referred to.

same period, exclusive of head office expenses, directors' fees and Government taxes, was: £7, 0s. 10d.

Including these overhead charges it was: £8, 16s. 10d.

Operations are conducted on a small scale at all three mines which accounts for the heavy overhead charges.

The cost of producing an ounce of platinum from the ores of the Merensky Horizon, as developed in the Rustenburg district, has been variously estimated at from £5 to £8. Those best competent to judge put it down at about £6 per ounce, so far as the sulphide ore is concerned, after allowing for the price of the nickel and copper recovered as an offset against working costs.

It would appear, therefore, that if the figures and estimates given are correct, South Africa has nothing to fear in the competitive field from either Russia or Colombia.

If recent reports are correct, more serious competition may be expected from the International Nickel Company in whose Frood Mine near Sudbury, Canada, there has been opened up at depth an enormous orebody averaging, over a width of 150 feet, 4.5 per cent. of copper, 4.2 per cent. of nickel and 3.2 dwts. of palladium and platinum per ton. If this deposit is worked on a scale commensurate with its size, large quantities of palladium and platinum will be cheaply produced as by-products.

(d) The Platinum Resources of Russia, Colombia and Canada.

Russia, who before the war was responsible for some 92 per cent. of the world's annual production of platinum, has, as we have seen, again recovered her lead. Her present sales are at the rate of about 100,000 ounces per annum. The platinum is derived almost entirely from the alluvial gravel deposits of the Urals which are very extensive but of low grade, the richer gravels having long ago been worked out.

The known deposits are officially estimated to contain 7,000,000 ounces of the metal, but the reports of independent engineers who have visited the Urals place the reserves at a very much lower figure.

The bulk of the output is at present being obtained by means of big modern electrically operated dredges. Large quantities of the metal are, however, still being produced by *Starateli*, local peasants working on tribute on a small scale.

Finally, small amounts of platinum are also being recovered by crushing and concentration from the primary dunite occurrences of the Urals.

At the present time no crude platinum can be sold in Russia. The whole of the output goes to the state refinery at Sverdlovsk (Ekaterinburg), the output of which, as already stated, is handled by the *Edelmetalle-Vertriebs Aktiengesellschaft* of Berlin.

The Colombian reserves are also from all accounts very large, but here too the gravel is of low grade. About one half of the Colombian output is derived from modern dredges and the other half by hand washing by primitive means on the part of natives.

The ore reserves of the Sudbury field in Canada are enormous, but so far notable amounts of the platinum metals have only been proved to be present in the lower levels of the Frood Mine.

We may next discuss what the writer considers to be some of the more pressing needs of the South African platinum industry.

Need for Co-operative Restriction of Output and Price Stabilisation.

If the figures as to cost of production given in a previous section are correct, it is clear that South Africa could, if necessary, undersell both Russia and Colombia.

The question then arises whether she should do so, or whether she should aim at co-operative restriction of output with these countries in an endeavour to maintain prices at a comparatively high level.

The first course would mean producing and selling as much platinum as possible, at as low a price as is practicable, with a view to crippling the Russian and Colombian industries; at the same time relying on the low price greatly to increase the demand for the metal for chemical and industrial purposes. In other words it aims at placing on the market unrestricted quantities of platinum at a comparatively low price. This course is freely advocated in some quarters where it is contended, in opposition to the opinions already quoted, that a considerable decrease in price would be bound to lead to greatly increased consumption of the metal.

Others, including the present writer, are strongly in favour of the second course. They contend that it would be suicidal to attempt to undersell Russia as she would probably retaliate by throwing on the market her reserve of platinum, estimated to be worth about £2,600,000, thereby rendering the South African industry unprofitable for three or four years at least.

In the writer's view, the obvious course is for the leading producers to arrive at an understanding as to outputs and prices. It is very desirable from every point of view that the price of platinum should be stabilised by international agreement. If this were done it would not only greatly stimulate the use of the metal, but might open up a field for its employment vastly more important than any of them, namely, as a backing for paper currency to supplement the world's wholly inadequate stock of gold.

If, for instance, the price of platinum were stabilised by international agreement at, let us say, £10 per ounce, or in other words, if it were standardised at this figure in terms of gold, and the leading platinum producing nations, moreover, agreed to limit their annual sales of the metal to a definite quantity, the writer sees no reason why reserve and central banking institutions should not build up great platinum reserves against which they could issue ordinary notes, and why in particular the South African Reserve Bank should not lead the way in this direction. The suggested introduction of a new form of bimetallism will probably be regarded with horror and consternation by bankers and treasury officials, but they are admittedly among the most conservative of men, and the fact remains that, after the revolution, Russia rehabilitated herself financially largely by the skilful use of the big reserves of platinum which she then commanded, and this at a time when the price of the metal was fluctuating considerably.

As a first step toward anything in this connection it would be necessary to call an international conference of platinum producers. As the venue for such conference the writer would suggest South Africa, as the delegates of other countries could then convince themselves of the magnitude of the potential reserves of the metal, and also, it is to be hoped, of our ability by then to produce at a comparatively low price. There is, however, another reason why South Africa should be chosen, and that is that we have at the head of our platinum industry

some of the leaders of the South African diamond industry which has given the world an object lesson in the control of output and sales of another luxury commodity. These men would find it easy to formulate a policy for the platinum industry. Indeed, all that is needed here is to get other producers to recognise and adopt what were recently enunciated by Sir Ernest Oppenheimer as the cardinal principles of the diamond trade, namely, (1) strict control of output, and (2) sale, so far as possible, through one channel only.

The latter would necessarily involve the formation of an international selling organisation on the lines of the Diamond Syndicate, or the remodelling of the existing Platinum Syndicate.

Apart from this steps should at once be taken to promote and expand the use of the platinum metals and particularly of palladium. This valuable and beautiful metal will be produced in large quantities by the South African mines, and will undoubtedly become a drug on the market unless the demand for it can be very greatly stimulated. What can be done in the direction of increasing the demand for metals has been amply demonstrated by the nickel and copper producers of America. Finding their respective industries over-capacitated after the Great War, they at once set about by scientific research and propaganda to find new uses and applications for these metals, the big companies establishing special departments for this purpose. Results have exceeded all expectations. The demand for copper has increased by nearly 100 per cent. during the last nine years, and the price at present is higher than at any time during this period. In the case of the nickel industry too there has been a very considerably increased demand, and the price at present is higher than it has been for years.

The writer would suggest that a committee composed of the best scientific and commercial brains of the country be appointed forthwith to inquire into ways and means of promoting the use of the platinum metals, and that the Government and the controlling mining houses should place ample funds at its disposal.

It should be stated that the Soviet Government have already an organisation of this nature in the Institute for the Development of Platinum and Other Noble Metals (known as the Platinum Institute).

Another desideratum of the South African industry, so soon

as it is producing on a really big scale, will be a platinum refinery, run on the lines of the great Rand (Gold) Refinery, near Germiston. Such a refinery would be of the greatest benefit to producers, as they would then be assured of getting full value, not only for their platinum and palladium, but for the other valuable metals, such as rhodium, ruthenium and iridium, by which they are accompanied. Russia found herself forced to take this step after the Great War and, as previously stated, is at present exporting only refined platinum metals.

Conclusion.

Holding the views that he does the writer sees no reason why, if some of the more important recommendations here made are acted upon, the South African platinum industry should not develop into something really big and practically permanent. If, on the other hand, we are content to adopt a policy of *laissez-faire*, all that can in his opinion be hoped for is a maximum output of perhaps 100,000 ounces per annum, divided among five or more producing companies, with constant price fluctuations and other disturbing elements to unbalance the industry.

CHAPTER XXIII

THE MORE IMPORTANT PLATINUM MINING COMPANIES

DURING the great platinum boom of 1925 over fifty companies were floated in the Union of South Africa to exploit the deposits of the Bushveld Complex and Waterberg District. For many of these flotations there was not the slightest justification, and their names have faded from our memory.

Other concerns have been absorbed by more prosperous companies; others again have transferred their activities from the Lydenburg district to the more favourably circumstanced Rustenburg district, while retaining the original names of their Lydenburg properties. Yet others, owing to the exhaustion of their funds, have suspended operations and in many instances will never resume them.

The following is a list of the more important actual and potential producers in existence at the present day:—

- (1) *Potgietersrust Platinums, Limited.*
- (2) *The Lydenburg Platinum Areas, Limited.*
- (3) *Onverwacht Platinum, Limited.*
- (4) *Waterval (Rustenburg) Platinum Mining Company, Limited.*
- (5) *Platinum Exploration Company, Limited.*
- (6) *Transvaal Consolidated Land and Exploration Company, Limited.*
- (7) *Elandsfontein Platinum, Limited.*
- (8) *Colonial Mining Development Company, Limited.*
- (9) *Northern Platinum Exploration, Limited.*
- (10) *Platinum Proprietary Company of Lydenburg, Limited.*

(1) **Potgietersrust Platinums, Limited.**—Capital, £1,962,500 in 7,850,000 shares of 5s. each, fully paid.

This company, originally formed to work the platinum deposits north-north-west of Potgietersrust, has, during the past two and a half years, acquired the properties of the *Premier Rustenburg Platinum, Limited*, the *Steelpoort Platinum Syndicate*,

Limited, and the *Eerstegeluk Platinum Mines, Limited*, all situated in the Rustenburg district.

It has by far the most extensive holdings of any of the South African platinum companies. These include:—

1. *Farms Owned.*

Potgietersrust District	. Witrivier, No. 282.
	Overysel, No. 403.
	Vaalkop, No. 256.
	Twefontein, No. 1033.
Rustenburg District	. Swartkop, No. 355, undivided 1/84th portion.
Lydenburg District	. Eerstegeluk, No. 348.

2. *Discovery Rights.*

Potgietersrust District	. 14 rights totalling 459 claims.
Rustenburg District	. 19 " " 418 "
Lydenburg District	. 1 " " 39 "

3. *Mineral Rights Owned.*

Potgietersrust District	. Farm Zwartfontein, No. 121.
	Farm Twefontein, No. 1033 ; undivided half interest in mineral rights over Portion A, in extent 200 morgen.
Rustenburg District	. Farm Kroondal, No. 177 ; portions in extent 842 morgen, 159 square roods.
	Farm Klipfontein, No. 538 ; portions in extent 62 morgen, 105 square roods.
	Farm Schildpadnest, No. 233.
Lydenburg District	. Mynpacht on farm Eerstegeluk, No. 348, in extent 471 morgen, 447 square roods.

4. *Mineral Rights Leased.*

Potgietersrust District	. Town Lands of Potgietersrust, in extent 6000 morgen, for a period of twenty years, renewable for a further twenty-one years.
Rustenburg District	. Town Lands of Rustenburg, in extent 6799 morgen, for a period of twenty years, with right of renewal for further twenty years.
	Farm Turffontein, No. 297.
	" Bosfontein, No. 489.
	" Uitvalgrond, No. 334.
	" Vaalkop, No. 677.
	" Doornspruit, No. 878.
	" Klipfontein, No. 538

5. *Prospecting Rights.*

The company also holds prospecting rights over an area of 53,288 morgen in the Potgietersrust district, and over an area of 34,930 morgen in the Rustenburg district.

The company is at present conducting mining and treatment operations on the farm Zwartfontein, No. 121, north-north-west of Potgietersrust, and is actively developing the Kroondal-Klipfontein Mine near Rustenburg.

At the Zwartfontein Central Mine a reserve of some 300,000 tons of payable ore has been opened up. The treatment plant has, as previously stated, a capacity of 100 tons per diem. It is producing approximately 4000 ounces of platinum and palladium per annum.

At the Kroondal-Klipfontein Mine, near Rustenburg, a very big reserve of ore has been opened up. A treatment plant with a capacity of 6000 tons per month which, it is estimated, will produce 26,000 ounces of platinum metals per annum, is being erected here. It will, it is hoped, be in commission by the end of the year.

The company have also a valuable property on Schildpadnest, No. 233, in the northern part of the Rustenburg district, on which a considerable tonnage of payable ore has been developed. This property is at present lying dormant, but could easily be brought to the stage of production.

The Zwartfontein plant of the Potgietersrust Platinums, Limited, has been operated continuously since September 1926. Up to 4th December 1928 there had been produced 1122 tons of concentrate estimated to contain 4516 ounces of platinum, 4767 ounces of palladium, 193 ounces of other platinum group metals, 284 ounces of gold, 44 tons of nickel, and 23 tons of copper; the estimated aggregate value of these metals being £110,000. So far there have been no sales of either precious or base metals.

On 30th September 1928 the Potgietersrust Platinums, Limited, had on deposit at their bankers cash to the amount of £308,652, 7s.

(2) **The Lydenburg Platinum Areas, Limited.**—Capital, £320,000 in 1,600,000 shares of 4s. each, of which 1,460,000 shares are issued.¹

This company, a subsidiary of the *New Consolidated Goldfields, Limited*, was formed in 1926 to take over the Lydenburg properties of the *Lydenburg Platinum, Limited*. These properties are given on the following page.

¹ The original capital of the Company was £1,460,000. This was reduced to the present figure in 1928.

1. *Freehold and Mineral Rights.*

Farm Maandagshoek, No. 148 (on this property a mynpacht of 998 morgen, werf of 100 morgen and owners reservations of 222 morgen have been granted and belong to the company).

Portion of farm Eerstegeluk, No. 348.

Portion No. 5 of farm Kalkfontein, No. 22.

Farm Chieftainsplain, No. 169.

2. *Freehold.*

Portion of farm Kalkfontein, No. 22.

Portion of farm Paschaskraal, No. 126.

3. *Mineral Rights.*

Farm Paschaskraal, No. 126.

Farm Dwarsrivier, No. 86.

4. *Discovery Claims.*

Paschaskraal, on Merensky Horizon	.	.	.	50 claims.
" on Chrome Horizon	.	.	.	50 "
Twyfelaar, No. 172, on Merensky Horizon	.	.	.	33 "
Winnaarshoek, No. 349, on Merensky Horizon	.	.	.	34 "
Driekop, No. 170, on Merensky Horizon	.	.	.	100 "
Maandagshoek, No. 148, on Merensky Horizon	.	.	.	50 "
" " on Chrome Horizon	.	.	.	50 "
Mooihoek, No. 147	.	.	.	134 "
Eerstegeluk, No. 348	.	.	.	10 "
Dwarsrivier, No. 86, on Merensky Horizon	.	.	.	50 "
" " on Chrome Horizon	.	.	.	50 "
Thorncliffe, No. 217	.	.	.	37 "

5. *Options on Mineral Rights.*

Farm Hendriksplaats, No. 357 (Precious and Base Metals).

The company is working the Mooihoek and Driekop dunite pipes and treating the ore won at the central plant on Maandagshoek. During the year ended 30th June 1928 there were milled 36,924 tons of ore. The estimated recovery of platinum metals was 7750 fine ounces. Operations resulted in a profit of £42,965, reducing the debit at Profit and Loss Account brought forward from the previous year to the sum of £153,909, 9s. 6d.

At the end of the financial year the company had on hand concentrates of an estimated net value of just over £20,000.

(3) **Onverwacht Platinum, Limited.** — Capital, £450,000 in 900,000 shares of 10s. each, all shares issued and fully paid.

This company was incorporated on 12th April 1926, to acquire the Onverwacht Mine and the mineral rights over the farm.

A reduction plant with a capacity of 100 tons per diem was, as already stated, started on 13th January 1926, and has been in operation continuously ever since. During the year ended 30th June 1928, there were milled 27,297 tons of ore yielding 6835.8 fine ounces of platinum and allied metals. The profit on working for the year amounted to £33,975. Two dividends Nos 3 and 4, totalling $7\frac{1}{2}$ per cent., were declared and absorbed £33,750, bringing the total dividend distribution to date to $27\frac{1}{2}$ per cent.

(4) **Waterval (Rustenburg) Platinum Mining Company, Limited.**—Capital (authorised) £162,500. Capital issued, £156,750 in shares of 10s.

This company, another subsidiary of the *New Consolidated Goldfields, Limited*, was formed in 1928 to take over from the *Lydenburg Platinum, Limited*, the farm Waterval, No. 1022, adjoining the Rustenburg Town Lands, on which a very promising mine is being opened up on the Merensky Horizon.

A steam power plant has been completed, and a treatment plant with a capacity of 10,000 tons per month is in process of erection. The process to be used has not as yet been disclosed.

(5) **Platinum Exploration Company, Limited.**—Capital, £100,000 in 400,000 shares of 5s. each, of which £368,000 have been issued.

The company owns fifty discovery claims on the farm Swartklip, No. 988, situated in the Rustenburg district of the Transvaal, and holds prospecting contracts over this farm and the adjoining farm Turfbult, No. 989. A lease over the portion of the farm Swartklip underlain by the Merensky Horizon has been applied for in terms of Clause 7 of the Reserved Minerals Development Act of 1926.

The company have opened up what promises to be a very rich mine on the Merensky Horizon, and have developed a considerable tonnage of oxidised and sulphide ore.

A treatment plant with a capacity of 250 tons per diem is being erected and should be in commission by June 1930.

(6) **Transvaal Consolidated Land and Exploration Company, Limited.**—Capital, £465,119 in 930,238 shares of 10s., all issued and fully paid.

This company has large holdings on the Lydenburg and Rustenburg platinum fields. It is at present systematically opening up the Merensky Horizon on the farms Brakspruit, No. 393, and Boskoppie, No. 685, situated respectively east-south-east and north-north-west of Rustenburg. Results have been very gratifying, and development is at present being pushed ahead in the sulphide zone on both properties.

(7) **Elandsfontein Platinum, Limited.**—Capital (authorised) £300,000; capital issued £100,501, 15s. in shares of 5s. each.

This company, a subsidiary of the *African and European Investment Company, Limited*, is developing a valuable platinum mine on the Merensky Horizon on the farm Elandsfontein, No. 820, in the Rustenburg district. The erection of a treatment plant is under consideration.

(8) **Colonial Mining Development Company, Limited.**—Nominal Capital, £10,000.

This company, as previously stated, is systematically opening up what is reported to be a promising stretch of the Merensky Horizon on the farm Roodekopjes, No. 171, south of Marikana station in the Rustenburg district.

(9) **Northern Platinum Exploration, Limited.**—Capital, £560,000 in 2,240,000 shares of 5s. each; all the shares are issued and fully paid.

The company, a subsidiary of the *Anglo-American Corporation of South Africa, Limited*, was formed in 1925 to acquire from the *Lydenburg Consolidated Platinum Mines, Limited*, the farm Zeekoegat, No. 312, in the northern part of the Lydenburg district of the Transvaal, together with options over adjoining farms. Most of the options have been abandoned.

The company at present actually owns:

Forty-one discovery claims on the farm Zeekoegat, No. 312.

A mynpacht of 715 claims on the farm Zeekoegat, No. 312.

Thirty discovery claims on the farm Middelpunt, No. 2.

Mineral rights over the farm Leeuwkop, No. 528.

A considerable amount of development work was done on Zeekoegat, which indicates some 700,000 tons of ore carrying an average of 4.77 dwts. of platinum metals per ton. Mining operations were discontinued in September 1927.

The company has a substantial share interest in *Potgietersrust Platinums, Limited*.

(10) **Platinum Proprietary Company of Lydenburg, Limited.**—Capital, £100,000 in 100,000 shares of 20s. each; all issued.

The company owns discovery claims on and the mineral rights over the farm Helena, No. 220, formerly St Edmunds, in the Lydenburg district, and an option over the mineral rights on Richmond, No. 227.

A considerable amount of work has been done on the Merensky Horizon on these farms, particularly on Helena.

Present development points to the existence between the Main Adit and the No. 3 Winze on this farm of a block containing 60,000 tons of ore averaging 5 dwts. of platinum metals over 24 inches. This ore is only partly developed, but, by extending the Main Adit for a distance of about 1200 feet and sinking two winzes, the writer has estimated that there could be developed in this sector 160,000 tons of sulphide ore and 50,000 tons of oxidised ore. If existing exposures can be taken as a criterion, the bulk of the sulphide ore should average 5 dwts. over 24 inches, and the oxidised ore should average in the neighbourhood of 4 dwts. over 24 inches.

STATISTICS OF PRODUCTION, UNION OF SOUTH AFRICA

(a) Platinum Metals exclusive of those in the "Osmiridium" of the Witwatersrand.

The sales of platinum metals derived from the deposits of the Bushveld Complex up to the end of 1928 were as under:—

Year.	Ounces (Troy).	Value (Sterling).	Value per Ounce.
1926	4,951·347	93,307	£ s. d. 18 16 11
1927	10,431·397	144,191	13 16 5
1928	17,827·628	241,110	13 10 5

These figures relate to actual sales only. Thus, the official production of platinum metals during 1928 was 23,662·908 ounces.

The difference is represented mainly by the unsold platinum metals contained in the concentrates shipped by the Potgietersrust Platinums, Limited. The figure is also exclusive of the platinum in the "osmiridium" concentrate produced on the Witwatersrand, which contains between 10 and 11 per cent. of this metal (see below).

(b) "Osmiridium."

The production of "osmiridium" by the mines of the Greater Witwatersrand to the end of 1928 has been as follows:—

Year.	Production (Ounces Troy).	Sales.		Value per Ounce.
		(Ounces Troy).	(Sterling).	
1921	...	509	6,801	£ s. d. 13 7 3
1922	...	761	13,165	17 16 0
1923	3,101	1,784	43,528	24 8 0
1924	5,673	4,107	102,886	25 1 0
1925	5,490	6,055	170,995	28 4 9
1926	6,228	6,360	96,734	15 4 2
1927	5,473	5,653·18	58,137	10 5 8
1928	5,670·637	5,913·45	85,692	14 9 9

The percentage composition of the “osmiridium” sold during 1927 was as follows:—

Metal.	Per Cent.	Expressed as Weight of Metal.
		Fine Ounces (Troy).
Osmium	30.51	1,724.902
Iridium	28.32	1,601.031
Ruthenium and Rhodium	13.51	763.879
Platinum	10.74	606.939
Gold	2.62	147.942
Balance (undetermined)	14.30	808.487
Totals	100.00	5,653.180

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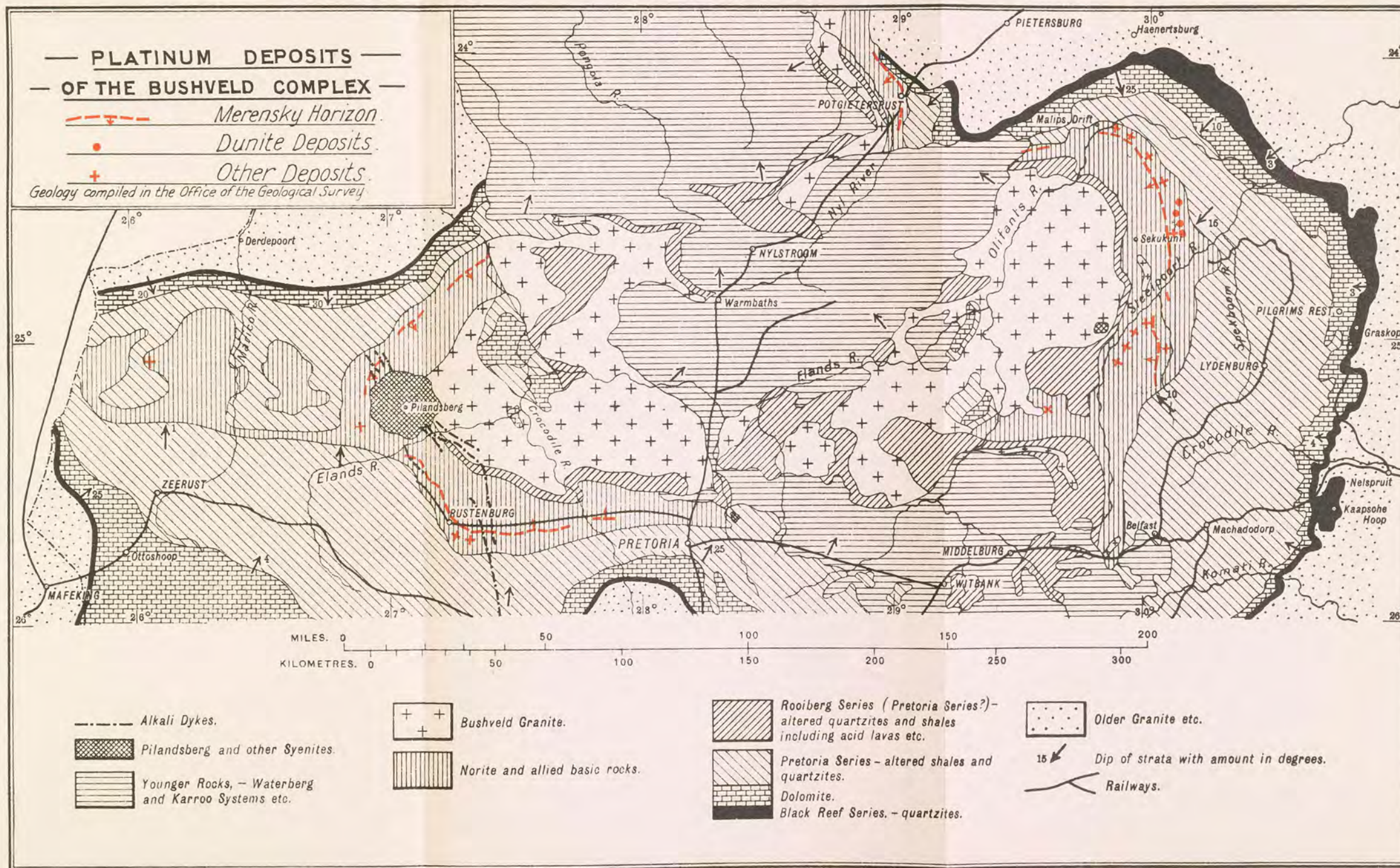
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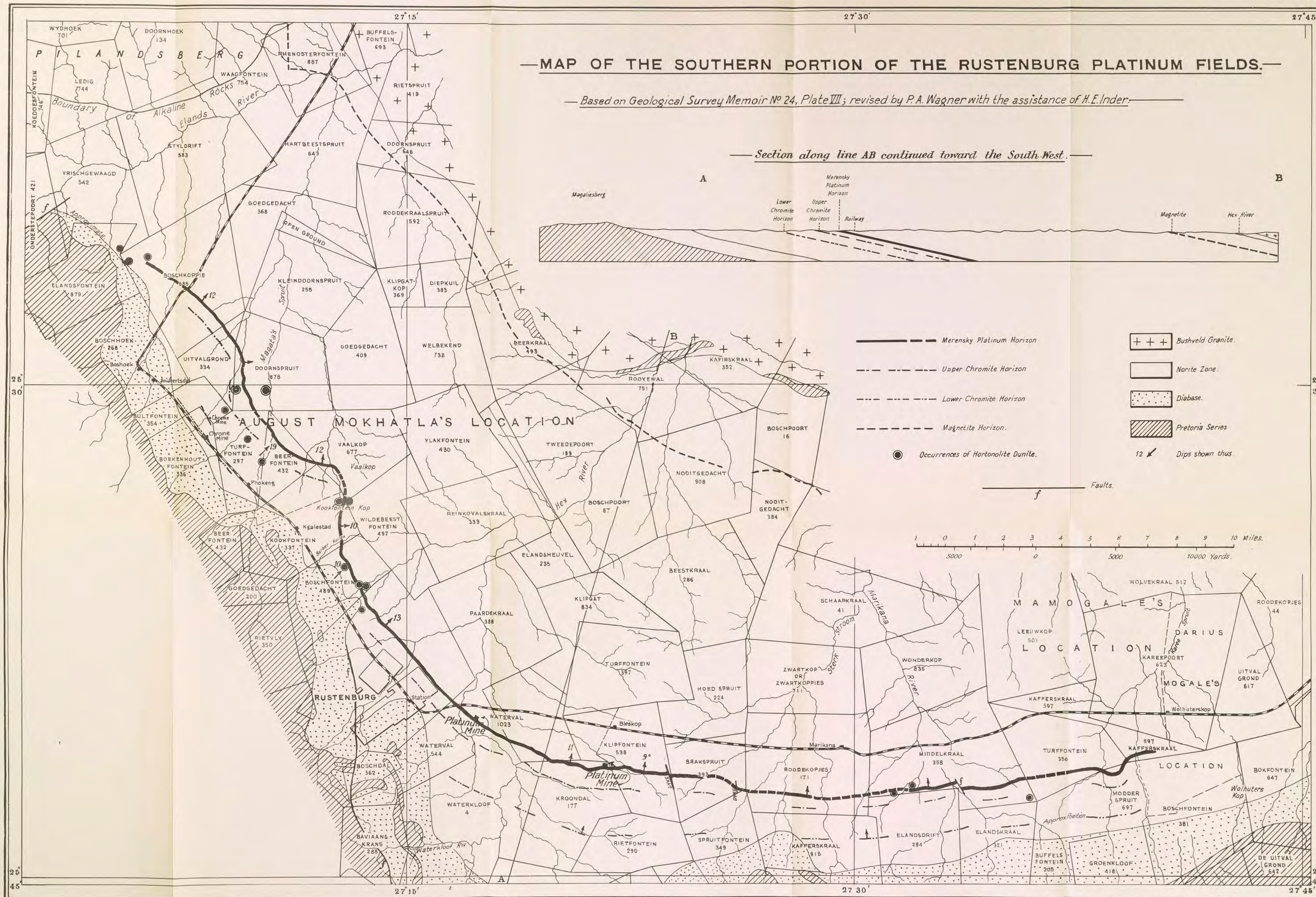
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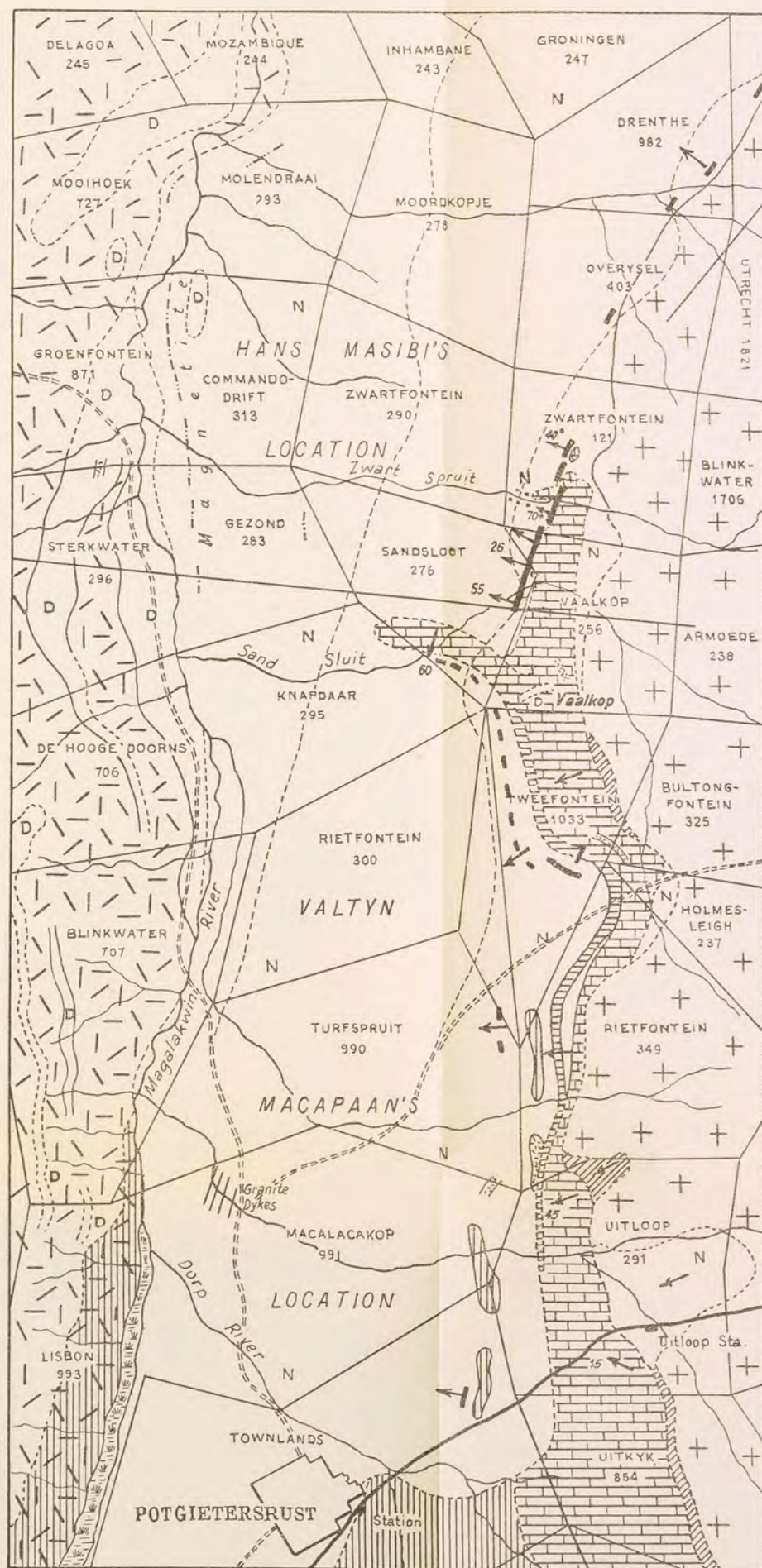
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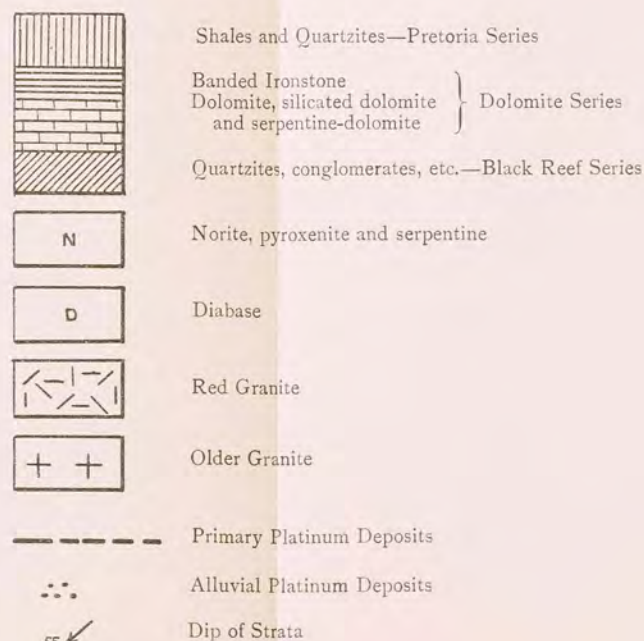




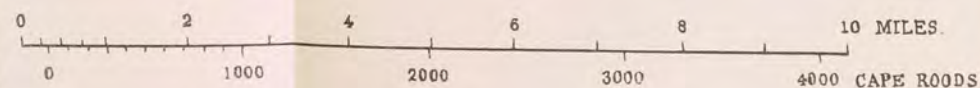
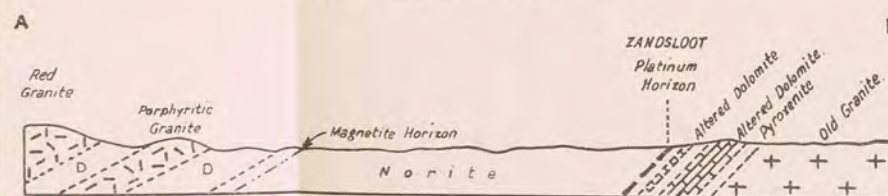


MAP of portion of the POTGIETERSRUST PLATINUM FIELDS showing PRIMARY AND ALLUVIAL DEPOSITS AS AT PRESENT KNOWN.

Compiled by P. A. WAGNER, with the assistance of Dr E. REUNING.



Section across Norite Zone along line A.B., showing position of Main Platinum Horizon.





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